Building Inter-Personal Competence in Architecture and Urban Design Students through Smart Cities at a Higher Education Institution

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Received: 30 September 2019; Accepted: 12 December 2019; Published: 15 December 2019

Abstract: As the smart city concept and applications continue to evolve, traditional architects and urban designers are facing an increasingly uncertain future. This paper outlines an innovative educational format to bolster and perpetuate the interdisciplinary nature of architects and urban designers that resonates with both sustainable development (SD) and smart cities (SCs). By applying ‘connective knowledge’ to the concept of interdisciplinarity education, a method was established that uses the SC concept to expand upon and create a bridge between distant disciplines in the context of higher education sustainable development (HESD). As a complementary educational pedagogy to the ‘whole institution approach’ to reduce barriers in higher education institutions (HEIs), this paper highlights an opportunity to apply the SC concept as a basis to construct an interdisciplinary design workshop to focus on building inter-personal competence, targeting university-level students majoring in architecture and urban design. The design workshop used microcontrollers and sensors as these are scalable and easily learnt building blocks of the Internet of Things and SCs. The inter-disciplinary workshop ran for 16 weeks with 14 students majoring in architecture and urban design and electrical engineering. Based on interviews and course evaluations, the experiment was vetted using capacities of inter-personal competence in sustainable development. A series of insights and findings from the design workshop indicated positive initial outcomes that were used to form a set of working criteria for the interdisciplinary design workshop. Future work will include structuring empirical data collection and analysis and expanding collaborations with other distant disciplines such as public administration and social innovation, as delineated by the SC concept.

Keywords: interdisciplinary; transdisciplinary; interpersonal competence; smart city; higher education institution; education for sustainable development; microcontroller; internet of things

1. Introduction

Architects and urban designers have been feeling threatened by the rapidly developing concept of smart cities (SCs). The American Institute of Architects (AIA) magazine featured a special section on smart cities in January 2019 [1], and a speech to the European Commission by Rem Koolhaas, a Pritzker Award laureate, best illustrated how architecture and city-building professions feel about the latest development of smart cities: “I had a sinking feeling as I was listening to the talks by these prominent figures in the field of smart cities because the city used to be the domain of the architect, and now, frankly, they have made it their domain” [2].

Within a decade, the culmination of the SC as a major leitmotif is striking as well as worrisome as numerous scholarly articles have criticized the current SC phenomenon [3–8]. For some, the smart city’s motives and drive are funded by the large technology giants trying to monetize public data [5–7], and for others, it is no more than a branding exercise by politicians and developers [3,4,6,8]. However, SCs provide an illusion armed with advanced technology and ubiquity that supersedes the visions of

sustainable city and resilient city. The SC is a concept that encompasses all the previous urban ideas including the sustainability and resilience of the urban environment [9–11]. This ubiquity is manifested in the global proliferation of transnational adaptation of the concept and relevant initiatives [8,9]. The concept of ‘smart sustainable cities’ has emerged as a response to global trends and issues such as sustainability, urbanization, and technological innovation [12–15]. Such a rapid transformation of SC to include environmental sustainability, which was lacking in the widely accepted definition of SCs [16], illustrates the speed and breadth of the SC’s capacity to accommodate and the willingness from other academic as well as professional disciplines to partake in the shaping of the SC concept.

Despite sustainable development (SD) and SC sharing a seemingly common goal of searching for urban sustainability [16,17], since the two concepts stem from different backgrounds and core disciplines, it is hard to imagine a smooth convergence of the two paradigms of professionals and academic tribes. This uneasiness between the two can explain the earlier comment by Koolhaas about the feeling of being threatened, as architects’ and urban designers’ traditional domain of city-making is being challenged by the professionals from Internet and Communication Technology (ICT) and data scientists. Instead of looking for differences, this article urges to look for a common theme between the two concepts; both SD and SC strongly emphasize interdisciplinarity to achieve innovative solutions and knowledge production [18,19]. Hence, interdisciplinary collaboration underpins the global endeavor to find the ultimate goal—the sustainability of our future environment.

Instead of highlighting the differences to mark territories between SD and SC, the aim of this study was to demonstrate that the two concepts can complement one another by expanding and improving the interdisciplinarity and transdisciplinarity of SD education for university students majoring in architecture and urban design (A/UD). The importance of interdisciplinarity and transdisciplinarity in both SD and SC cannot be understated [11,18,19]. The aim here was to design a workshop to prepare students to be better ‘agents of change’ with an awareness of the rapidly changing and unpredictable future.

This research draws upon both philosophical and theoretical chapters by Peters and Wals (2013) on the critical role of interdisciplinarity in education for sustainable development (ESD). In a chapter of the book, titled *Trading Zones in Environmental Education: Creating Transdisciplinary Dialogue*, the authors stated that “facilitating and pursuing sustainability is not just a scientific and technical project . . . it requires an embrace of epistemological pluralism that engages multiple ways of knowing, and multiple forms of knowledge” [20], p. 81. Additionally, the concepts and tools set forth by Peters and Wals “are in many ways deeply countercultural. They seriously challenge business as usual—not only in higher education and the academic profession, but also in other human systems such as government and industry” [21], p. 99. In line with the recommendations provided, the author aimed to propose an interdisciplinary design workshop focused on building the sustainability capacity in students majoring in architecture and urbanism through embracing epistemologically extraneous groups of knowledge such as SCs.

This paper shares the progress and steps used to frame the discussion of the definition and theory behind interdisciplinarity and the design of an interdisciplinary design workshop for university-level students. Based on the key findings and experience from the initial interdisciplinary design workshop between A/UD and electrical engineering (EE), the ongoing research aims to produce an array of alternative strategies and recommendations for imparting sustainable competencies in higher education institutions (HEIs) by expanding the design workshop include other distant disciplines that are represented in SC concepts such as data engineering, social science, economics, and health.

As ESD continues to shape the culture of education and learning for the 21st century, another goal here was to search for an innovative educational format for building a generation of architects and researchers prepared to embrace new concepts like SCs and others that will follow. To successfully achieve this objective, I started by evaluating and challenging the current protocols and initiatives of the interdisciplinary collaborations. An alternative format for transcending the level of cross-disciplinary

collaborations should be provided that can harness and perpetuate the ESD grounded on the core principles of pursuing sustainability.

2. Framework and Methodology

This research builds upon the wealth of research on both SD and SCs. Therefore, instead of providing an in-depth analysis and critique of various perspectives on the two paradigms, the focus here was on interdisciplinarity and its relationship with SD and SC. Through the work of Ahvenniemi et al. (2017), the comparison between SD and SC helped to identify the elements that can supplement the weaknesses and shortcomings of the two from the perspective of sustainability education [16]. To frame the discussion, a thorough and in-depth literature review on the higher education of sustainable development (HESD) was conducted to gain insight into the gaps and opportunities in the current state of HESD. Then, interdisciplinarity in HESD was reviewed to search for links in the opportunities of SC and to expand these to address sustainability education.

Two studies helped to formulate the methodology used to illustrate the novelty of this research and validate the proposed inter-disciplinary design workshop with key competencies in sustainable development. Two notable articles are provided. First, Prialux et al. [22] analyzed the current state of interdisciplinary collaborations and recommended breaking the preconceived idea of cross-disciplinary collaboration into the cycle and type of knowledge expected from interdisciplinary collaboration. This perspective outlined new and fresh aspects from which to approach interdisciplinary education. Second, Wiek et al. [23] outlined five key competencies of ESD, and of the five competencies, their findings highlight the significant role of interpersonal competence for ESD which was applied to verify and validate the outcomes from the initial inter-disciplinary workshop.

2.1. Interdisciplinarity in ESD

The Johannesburg World Summit on Sustainable Development (WSSD) in 2002 marked a pivotal moment for HESD. This is when HESD received international attention and was placed at the forefront of delivering sustainable education to foster a new generation of ‘agents of change’ [24,25]. After almost two decades, while much progress has achieved, the developed pedagogy and innovative educational curricula have not been implemented, or implementation has been sluggish [26]. Although structural, cognitive, and normative barriers [27] exist in HESD, educators are slowly transforming the culture of education and learning with the concept of sustainability. Yet, at HEIs, the urgency for developing and rethinking education curricula in interdisciplinarity is repeatedly highlighted [28–31]. Peters and Wals (2013) eloquently emphasized the importance of interdisciplinary education at HESD and highlighted it as the ultimate challenge for HESD. What is required is higher education curricula and pedagogical practices that foster interdisciplinary and creative ways of thinking about human–environment interactions as a necessary pre-condition for achieving a sustainable future. These new, innovative educational approaches must facilitate genuine interdisciplinary thinking and must be conducive to the cultivation of agency, self-determination, critical thinking, reflective capacity, and the development of what might be called “a planetary consciousness” [30], p. 387.

A seminal work edited by Barth et al. [32], the Routledge Handbook of Higher Education for Sustainable Development, provides a comprehensive overview of HESD, and highlights HESD’s significance, notable research, and curriculum reforms and innovations with the goal to help educators and researchers. In Section 3, Michelson et al. (2015) analysis of the policies on ESD spans over four decades and 20 international policies on ESD. They illustrate how ESD has transformed over time and responded to the needs of educators and researchers on the ground and shares insights on how to deliver and structure effective ESD using three dimensions (policy, politics, and polity) and three approaches (whole-institution, interdisciplinary, and transdisciplinary). The simplicity of the analysis underscores the importance of discussing ESD from two approaches—the institution (whole-institution) and the interdisciplinary approaches (interdisciplinary and transdisciplinary). In other words, ESD policies have advocated for a two-pronged-strategy—breaking down organizational and structural

barriers within institutions and organizations [27,29] and building bridges between disciplines and between academia and practice [26–28].

2.2. Learning from Smart Cities

According to Ahvenniemi et al. (2017), “a general goal of smart cities is to improve sustainability with the help of technologies” [16], p. 1. To elaborate upon this succinct statement, they began defining urban sustainability to provide context for comparing SD and SC. By comparing eight smart city assessment and eight sustainable city assessment frameworks, the authors attempted to highlight the similarities and differences between the two concepts. They found that SC emphasizes economic and societal indicators whereas SD and urban sustainability focused on environmental indicators. An interpretation from the findings may be that SCs’ economic and societal motives can enhance the current ESD aim to address all forms of environmental, economic, and social sustainability.

Angelidou (2015) referred to the two SC strategies as ‘urban future’ (hard infrastructure) and ‘knowledge and innovation economy’ (soft infrastructure). The convergence of the two is the ultimate goal of a SC [19]. To deliver such frameworks, the knowledge on vastly different scales and dimensions must be integrated; this implies the incorporation of distant disciplines, such as engineering and social science. Sustainable development, in theory, also encourages interdisciplinary and transdisciplinary collaborations [20,26,30]; however, in the case of SC, these interactions are expedited by the use of technology [15,16,18] and demands knowledge production limited to urban sustainability through transdisciplinary collaboration.

According to Formas (2006), the definition of “transdisciplinary is not a process that follows automatically from the bringing together of people from different disciplines or professions but requires an ingredient that some have called ‘transcendence.’ It also implies the giving up of sovereignty over knowledge, the generation of new insight and knowledge by collaboration, and the capacity to consider the know-how of professionals and lay-people on equal terms” [33], p. 42.

In SC, rapid progress in advanced technology provides a context in which no one discipline can claim dominance as it is still evolving and developing. Thus, SC provides an ideal environment for productive interdisciplinary collaboration plus hopes for transdisciplinary collaboration and research.

2.3. Interdisciplinary Learning

For architects and urban designers, interdisciplinary collaboration is integral to their profession and practice. Thus, most professionals and academics in the field consider themselves well equipped to organize and execute interdisciplinary collaboration and cross-sector integrations. However, the difference between the interdisciplinary collaborations in the context of sustainable education was summarized by Howlett et al. (2011) as follows: an interdisciplinary approach, which focuses on fostering different ways of looking at the world, can also create dissonance in the minds of learners and this is where, according to Wals and Jickling (2002), genuine and transformative learning occurs. Transformative learning is learning that effects change in our frames of reference or worldviews (Cranton 2006, Sipos et al. 2008). Indeed, the assumption of much sustainability education theory is that significant change in cultural worldview is necessary if more sustainable states of society are to be attained (Sterling, 2010) [29], p. 6.

Often interdisciplinary education is mistaken for multidisciplinary collaboration where information from different fields is discussed during the course of producing a solution. In the case of architecture and urban design collaborations at HEIs, as with most interdisciplinary collaborations, teaching an interdisciplinary approach tends to be dominated by single discipline and used to prove superiority over other disciplines [29,33,34]. As a response to this HE-level problem [25,27], Priaulx et al. (2018) provided a completely different perspective by examining the problem of interdisciplinary education by splitting the knowledge acquired by interdisciplinary education into two types of knowledge—of-knowledge and about-knowledge [22]. This suggestion instantly relieves the pressure from designing an interdisciplinary collaboration to impart all available discipline-specific

knowledge within a limited period of time. However, Priaulx et al. did not negate or undermine the whole institution approach to deliver and reinforce of-knowledge-centric initiatives and events to influence the students and faculty; however, citing structural and cultural limitations of this approach, much lighter and “rudimentary connective knowledge” between distant disciplines would offer a long-lasting motivation to university students who are in the formation stages, Priaulx et al. wrote where the aim is innovative futures research, we need to widen horizons and possibilities beyond the obvious, close-by, familiar, comfortable and tried and tested-and for that, we need to enable researchers to achieve insight “beyond current borders and thereby generate novel solutions to complex problems” [22], p. 11. Many studies reinforced the importance of sustainable education at the university level to create a new culture of sustainable thinking and acting [22,24,26,27]. ESD scholars have long advocated for the creation of a generation of researchers and practitioners who will lead societal transformation in dealing with the ‘wicked’ problem of the uncertainty of the future of our environment. This notion of growth and change in circumstances translates is a collaborative life-cycle of researchers and practitioners, as described by Prioulx et al., “we drew a distinction between “of-knowledge” and “about-knowledge” with respect to other fields, in order to conceptualize the different kinds of knowing that might prove necessary at different points of the collaborative life-cycle. In response to claims that individual researchers should “know more” field-specific knowledge to enhance collaborative work, we highlighted a range of concerns in respect of a level of cognition that is far too demanding in practice” [22], p. 15.

The recommendations by Priaulx et al. provide the perfect frame for the ongoing research to design an interdisciplinary sustainable education program for architecture students at HEIs to attain about-knowledge between distant disciplines to evoke interest and determine the value of interdisciplinary collaboration or “*connective knowledge*”.

For this research, SCs (or the *smart sustainable cities* concept) provide a context for structuring the collaboration between the two disciplines—architecture/urban design and electrical engineering—with an ultimate aim of imparting experience-based ESD for students from both departments. Additionally, to demonstrate the connective knowledge at work, critical differences between the ‘whole institution approach’ and ‘interdisciplinary approach’ in ESD are identified using the following set of characteristics: Type of Approach, Duration, Level of Collaboration, Type of Knowledge, and Range of Disciplines.

In the field of architecture and urbanism, one of the early high-profile institutional initiatives to introduce interdisciplinary collaborations in sustainable development was the Future Cities Laboratory. Beginning in 2010, the research covers a comprehensive list of urban topics and issues for building better future cities. This collaboration between the Swiss Federal Institute of Technology (ETH) and Singapore Universities (NUS and NTU) aims to develop high-level sustainability strategies and core knowledge, and to provide “pedagogic contributions to graduate and post-graduate education through the development of new didactic models, combining teaching, research, and practice” [35], p. 2. As stated in the research proposal, the research is “an interdisciplinary think tank dedicated to sustainable development and the advancement of knowledge in the key disciplines relevant to the formation of the built environment. The ambition is to promote future-oriented strategies in building technology, urban design, and territorial planning that implement new aptitudes regarding sustainability” [35], p. 8.

After reviewing the first 5 years of FCL initiatives, ‘FCL Phase 1’ was published on the FCL website [36] and a book, titled *Future Cities Laboratory Indicia 01*, edited by Cairns, the program director of FCL [37], illustrates thorough and wide-ranging topics on the sustainability of future cities. Yet, the expected outcomes and the boundaries of discussions appear to be situated ‘comfortably’ within the realm of traditional city-making. As the research is well underway, it is still too early to speculate on the success or failure of the whole institution approach of the FCL research.

However, it is not too difficult to come across “dilemmas and tensions” identified by Gosling (2001) and Mehling et al. (2019) in institution-led sustainable researches and collaborations [35]. As concluded by Mehling et al., the result of institution-level cross-sectoral collaborations is that “individuals engage in a narrative struggle about the organizational character of their partnership

and often the different organizational identities as project, organization or network compete with each other and cancel each other out” [27], p. 1. In other words, individuals spend more time and effort making sense of the aim and objective of the macro-level vision for the initiative than actually engaging in interdisciplinary collaboration to advance sustainable development. However, this study does not negate the importance and significance of breaking down the barriers in cross-sector and cross-operational management of HEIs to bring innovation to ESD [38]. Instead, this ongoing research aims to supplement the whole institution’s approach’s shortcomings with the parameters described by connective knowledge to provide a practical ESD that is appropriate for a higher education level.

Using the characteristics of connective knowledge described above, FCL is evaluated against the aims of the ongoing research Table 1.

Table 1. Comparison based on connective knowledge.

Category	Future Cities Laboratory	Inter-Disciplinary Design Workshop
Type of Approach	Whole Institution Approach	Interdisciplinary Approach
Duration	Funding (2010–2020)	collaborative life-cycle of researchers (learning phase at HE)
Level of Collaboration	Institution-level	Student-level
Type of Knowledge	Of-knowledge	About-knowledge
Range of Disciplines	Near disciplines (urban-related disciplines)	Distant disciplines (unrelated disciplines prior to smart cities (SCs))

2.4. Key Competencies for Sustainable Development

Within the field of education science, competence is an active and well-studied topic. A substantive body of research in competence research linked to SD has demonstrated what is and how to be effective at teaching and formulating ESD programs [23,32,39]. Although most of these studies helped to identify competencies for SD in various settings and formats, the results often provided lists of a varying number of competencies ranging from 5 to 19. For this research, a concise and novel effort by Wiek et al. (2011), featured also in the seminal literature on ESD, *Handbook of Sustainable Development in Higher Education* (2016), was chosen as it represents a principal set of competency framework for ESD [22]. The five competencies identified by Wiek are *System Thinking*, *Future Thinking or Anticipatory*, *Values Thinking or Normative*, *Strategic Thinking or Action-orientated*, and *Collaborative or Inter-personal*.

Of the above five key competencies of sustainability education, collaborative or inter-personal competence reflects the context of the present research. Inter-personal competence is “the ability to motivate, enable, and facilitate collaborative and participatory sustainability research and problem-solving” [23], p. 211. Wiek et al. (2011) referred to the fifth key competence as the “cross-cutting competence”, which supports the rationality and appropriateness of Priaulx et al.’s recommendation to seek connective knowledge at HEIs (Figure 1).

To further develop an analytical framework to validate the ability of the initial interdisciplinary design workshop to promote inter-personal competence, I analyzed unstructured interviews and course evaluations from the participants using the following six different concepts drawn from literature summarized by Wiek et al. [23], p. 211: (1) communication (Croften 2000, Byre 2000), (2) deliberating and negotiating (Sipos et al., 2008), (3) collaborating (de Haan 2006; Kevany 2007), (4) leadership (Ospina 2000, Kevany 2007), (5) pluralistic and trans-cultural thinking (de Haan 2006, Kelly 2006, McKeown and Hopkins 2003), and (6) empathy (de Haan 2006).

Figure 1. Competencies in education for sustainable development (ESD) and connective knowledge (adopted from Wiek, 2011).

3. Course Planning and Structure

3.1. Engineering Design Challenge

To structure an interdisciplinary design workshop, literature reviews were conducted mainly in engineering design education. Compared to design education in architecture, engineering design education literature is grounded in empirical data and both quantitative and qualitative analyses of improving design education for engineers. However, none of the previous literature addressed inter-disciplinary collaboration between electrical engineering and non-engineering discipline like architecture, which confirms the relevance of this current research.

Most studies have addressed multi-disciplinary collaboration and science, technology, engineering, and mathematics (STEM) engineering education [40,41]. Among the many works in the literature, the definition of excellent design challenges developed by the experts at the National Center for Engineering and Technology Education provides a clear set of aspirational values for a problem-based engineering design course [40]. Notable recommendations are authenticity and clearly structured but open-endedness of the course structure. These values were discussed as being the critical elements of a successful engineering design challenge. The list provides a set of criteria for improving engineering students' experience by immersion in several dimensions, such as understanding knowledge gaps, systems understanding, and bargaining between team members from different engineering backgrounds. Without being too overly critical and analytical, the whole design workshop's similarity to design-studio-based courses in architecture and urban design curriculum is striking. More impressive is how these two interdisciplinary collaborations address the core values of sustainable development education. Thus, the experiment applied a concept of key competencies for sustainable development.

The course chose to use microcontrollers, which refer to the main circuit boards to which sensors, actuators, and other modules like Wi-Fi modules can connect. Learning to operate a microcontroller is the first step toward understanding the basic concepts of the Internet of Things (IoT). The IoT is the defining element of the SC paradigm [42–44]. This hardware can collect and share data, which can then be analyzed to provide information to improve public safety, environmental conservation and protection, power management, and smart transportation systems [17–19].

From the beginning, overcoming the structural limitations of HEIs were necessary. Inter-departmental politics and organizational territories that deter cross-sector collaborations in HEI are common and well documented [27,29]. Apart from the organizational hurdles, the curricula in both departments are rigid and tightly programmed, so opening a preparatory course at the undergraduate level is challenging. Notably, the architecture program is evaluated and accredited by the Korean Architecture Accreditation Board (KAAB) every 5 years [45]. Every course has to address at least one out of twenty six [26] student performance criteria (SPC), and it is worth to mention that only one criterion concerns with teaching and learning the concept of sustainability and sustainable development [45].

This joint workshop between A/UD and EE began under the hypothesis that A/UD students and EE students can learn from each other. The ultimate goal of this collaboration was to engage students in gaining alternative perspectives ('about-knowledge') and learning how to build a long-term working relationship with students from another discipline ('collaborative life-cycle'). Although the participants were limited to two disciplines for this experiment, its aspiration to base the workshop on the SC encourages architecture students to reach out to other disciplines and learn to build individual capacity in self-reflection and self-motivation through interdisciplinary collaboration.

3.2. Course Objectives

The offered workshop was 16 weeks long and the class met once per week. There were no prerequisites to participation in the course, but for EE majors, students had to be in their final year. As for the students majoring in A/UD, students were enrolled in the graduate program majoring in either architecture or urban design. The graduate course was an advanced urban design course, which meant the students enrolled in ARC670 Urban Design Studio IV had taken three other urban design studio courses before taking this course. Most of the A/UD students were well aware of the urban design process as well as issues concerning the urban environment and urban infrastructure.

At the introduction and in the syllabus, the following several key objectives were shared:

- IDENTIFY issues and problems in an urban environment,
- EXPLORE and SHARE approaches from each other's fields,
- IDENTIFY the opportunities and limitations of applying technology,
- LEARN the hands-on skills required to implement and build prototypes, and
- RECOGNIZE the differences in how electrical engineers think.

The instructors set the parameters of the problem to be relevant to an urban outdoor environment and to combine a microcontroller to solve or improve existing urban problems, especially in urban infrastructure. At the end of the semester, each team had to produce a working prototype using Arduino UNO (Arduino AG, Ivrea, Italy).

3.3. Team Formation

Since it was the first time the experiment workshop was ever conducted, it was difficult to explain the course to the students without any visual or examples. However, the students had an easier time understanding that by participating in this interdisciplinary design workshop, students will gain knowledge about electrical engineers and potential outcomes of collaborating with EE professional in the context of Smart Cities. In total, five students from A/UD and nine students from EE enrolled in the workshop.

On the first day of class, the instructors provided an assignment to each student to identify a potential urban problem or issue that they would like to investigate. The topic had to address how technology can help to solve the problem. Because the students were from two different departments, it was foreseeable that the students would experience difficulties in forming a group without getting to know each other which required time. And with only 16 weeks to develop and produce prototypes, decisions were made early on to form teams around issues presented by the students and to open the

floor during the second class period for students to pitch a project idea that addressed an urban issue and how technology could improve the situation. Students were encouraged to form groups of three or maybe four students so that everyone in a team was proactive and played their role in the team. However, following the presentation, the class was divided into two teams with about 6–7 students per team.

3.4. Course Curriculum

Applying studio-based learning, which is fundamental to architecture education, students had a real site in which to place and situate their discussion Figure 2. The site was chosen because the local district had plans to apply smart technology to the neighborhood. The significance of the site was meant to help both A/UD and EE students to be grounded in a real-world problem with a physical location.

Figure 2. Site visit.

To reinforce studio-based learning, the instructors served as critics, and one teaching assistant (TA) served to help the students to produce sustainable and viable innovations. This teaching method was meant to screen out and weight alternatives that seemed achievable within 16 weeks of class. Each team had to meet every week, and the instructors provided comments on the design process, technical issues, and management (i.e., timekeeping and budget spending) Figures 2 and 3.

Figure 3. Weekly team meeting.

The similarity between the above diagram and the architectural design process is striking. Since the course was conducted jointly but managed separately, the course outline had to be loosely structured to comply with each department's completely different set of expectations. As such, the above design process diagram clarified the course's structure and provided a rough outline for the students to follow Figure 4.

Figure 4. Course outline.

The other commonality between A/UD and EE was found in prototyping. Students were encouraged to use the state-of-the-art Maker's Space available on campus to create concept models and the final prototypes.

Grading was performed separately. For A/UD students, there were no assignments; however, weekly progress reports documenting and archiving the team's progress had to be submitted. The weekly progress report contributed 20% to the final grade, the midterm presentation counted for 30% of the final grade, and the remaining 50% of the grade comprised the final presentation and final report.

4. Outcomes

4.1. Safety at Every Step

The team saw an opportunity to improve the current closed circuit television (CCTV) system connected to the emergency response network. They proposed a cheaper and more intuitive system to deter crime from occurring in dark and remote alleyways. A scalable alerting device was constructed to obstruct any potential crime from occurring via visual and psychological obstruction by applying the concepts from Crime Prevention Through Environmental Design (CPTED). The device allowed easy installation onto any street lamp post. The alert system was designed to react to high-pitched scream outside the normal average range lasting for at least 1.5 s Figure 5.

Figure 5. Safety every step team's circuit diagram.

The team designed an additional activation method other than a button, as a button was deemed to be unintuitive and unlikely to be used in case of an emergency. The proposed device can be easily attached to the existing street posts to detect and alert the nearby people in the area where criminal activity is occurring as shown in concept sketch Figure 6. Human screams will trigger flashing red and blue light emitting diode LED lights Figure 7 from the point of location. Using IoT technology, connected devices located up to 50 min radius will be activated. Furthermore, nearby connected CCTV will be activated to record the area to allow increase the chance of capturing footage of perpetrators escaping the crime scene.

Figure 6. Concept sketch.

The detection range of the microphone is the only limitation of the prototype device. With a single microphone attached, the range of accurate detection is less than 1 m and is single directional. If more microphones were to be attached or a multi-directional microphone was used, a wider detection range would be possible. The designer must consider the exponentially increasing complexity and power consumption. Addition to the complete package, the team delivered an edited video clip enacting how the device will function.

Figure 7. Prototype: flashing blue and red light emitting diode (LED).

4.2. Smart Drainage Cover

The goal of this project is to improve the existing storm water drainage covers that cause flooding due to misuse and lack of management before monsoon season. The effects of global warming are causing an increased occurrence of dangerous weather events such as typhoons, torrential rain, and heatwaves. Related to the global warming, localized heavy downpours have been observed with increased frequency in South Korea [46]. The City of Seoul suffered KRW 30.8 billion in damage due to local flooding in 2011 alone [47]. As such, the team focused on the news reports stating that many of these localized floods are caused by human activities covering up the storm water drains. The reasons for residents covering the stormwater drainage openings are mainly to reduce the stench from storm water drains and to prevent blockage by debris from the road. This problem is entirely human-made and can be solved by frequent maintenance; however, a lack of funding for maintenance encourages human intervention which ultimately causing a risk for localized flooding.

The team designed an entirely new cover for conventional storm water drainage with an integrated rainwater sensor linked to a microcontroller and an actuator that operates the simple opening and closing of the storm water drainage cover. To find a solution, the team identified a lack of knowledge in mechanical engineering. Even though students from the A/UD program did have experience in creating models, designing a storm water drainage cover proved to be more difficult than initially conceived. Eventually, four design alternatives were proposed and investigated (Figures 8–11).

Figure 8. Alternative #1: new steel cover design with rotating fins.

Figure 9. Alternative #2: add-on gravity-activated modular cells.

Figure 10. Alternative #3: smart drainage cover (embedded type).

After a careful vetting process, the team decided to develop the last option. The design was not the best solution; however, Alternative #4 (Figure 11) combined a microcontroller and an actuator with minimum mechanical engineering required. A moisture sensor coupled with an Arduino UNO main board allowed control of an actuator that moved a flap along a rail. The pinion and rake had to line up with enough distance and force, and all the mechanical components had to be embedded into the design of the frame and the flap.

Figure 11. Alternative #4: smart drainage cover (added-on type).

The initial concept model failed to function due to the selection of the model material. The flap did not slide due to friction between the flap and the frame. The Arduino UNO main board and moisture sensor functioned well, and the actuator responded to moisture. For the final prototype, acrylic was used to create the frame and the cover. However, knowing that these storm water drainage covers have to withstand cars driving over the smart cover, the material of the device was reconsidered.

During the final presentation, the prototype did not function as intended. The Arduino main board failed to work, but with a switch, the flap moved along the rail. The prototype was partly successful Figure 12.

Figure 12. Smart drainage cover team's prototype.

5. Evaluation

5.1. Course Evaluations

Korea University solicits students to complete course evaluations after every semester, and the student responses are made available to the instructional staff to evaluate whether they have taught the course at a satisfactory level and to provide feedback. Overall, class scores were exceptionally high. As the workshop was loosely structured and involved team effort, most students responded that they proactively engaged in the workshop and their participation level produced a high mark. Many A/UD students noted that they gained interest in the field of Electrical Engineering. Written feedback included an overwhelming number of commendations for organizing such a workshop. Furthermore, many students mentioned that they will try to learn more about Arduino. EE students' course evaluations were not available due to university regulations; however, the EE instructor shared that the overall response was positive and enthusiastic about the whole collaboration experience with the A/UD students.

5.2. In-Depth Personal Interviews

Face-to-face unstructured interviews were conducted to learn more about the students' own experiences. More importantly, these provided personal accounts of team management and team member dynamics that were not included in the weekly progress reports. For the interviews, the author chose to interview the team leaders from both teams. Both interviews lasted about an hour each.

5.3. Capstone Award

The Safety Every Step team won a Capstone Award, which is given to a team demonstrating excellent engineering design project every year. The team applied for the competition after the completion of the workshop and was among the 12 winning teams. This award confirmed that the

team produced a project that exhibited Capstone's aim, which is to educate students to be innovative and demonstrate the ability to solve problems with real-world applications [48]. Coincidentally, the aim and objective of Capstone courses share commonality with ESD.

6. Key Findings

Based on the evaluation, this section summarizes the lessons learned from conducting the inter-disciplinary workshop between A/UD and EE.

6.1. Team Forming

As expected, team forming played a critical role in shaping the outcome and team management. Despite the initial intention and suggestion by the instructors, students were divided into two teams. Because the students had no opportunity to mingle during class before discussing their projects of interest, about half of the EE students remained together. The other half of EE students were international students who started talking to the other international students from A/UD. At the end of the team forming session, those who would serve as team leaders were identified.

The team leader of the smart drainage cover (SDC) team was the oldest among the students in the course and enrolled in the Ph.D. program. Immediately, the undergraduate EE students were subordinate to the Ph.D. candidate's leadership, and this negatively impacted the team dynamics. Armed with experience in the architecture office, the team leader volunteered to manage and steer the team. The other factor that affected the team dynamics was the EE students' lack of experience in team work as well as their lack of motivation typical of undergraduate graduating class. At the beginning of the workshop, the team leader took the initiative and chose the problem out of three topics. The team did not realize how a lack of knowledge in mechanical engineering would play a significant role in problem-solving. Right after the problem was defined, the EE students proposed and tested the four alternatives, but with limited experience, the students became frustrated. The team leader offered to help, but the EE students refused. As a result, the team failed to integrate into one team.

The Safety Every Step (SES) team attracted international students, and the TA joined this team as a member. Because the TA had more experience than the students, they took the role of the team leader for the SES team. According to the team leader, this team had a long discussion at the beginning of the project about their experiences, interests, and skillsets. Through this exchange, students became aware of what everyone could do and where each participant was willing to invest time to learn. From the start, this team was fully integrated and understood each other quite well. Clearly, having the TA leading the development of Arduino helped; having the assurance that there was someone with technical expertise in Arduino helped the team dynamics. Throughout the course until the final presentation, this team demonstrated partnership and a fun working relationship. This team took the initiative to produce a video clip showing the testing phase of the prototype by the teammates. Such enthusiasm is an indication that good teamwork was present. The team leader informed us that the teammates still meet from time to time even though the workshop has finished. Forming teams proved to be a critical phase of the workshop. The team forming exercise sets the tone for the entire semester and ensured prolonged and even sustainable cross-disciplinary opportunities to collaborate on projects even after the course was over. At the HEI level, collaboration, due to students' limited experience and resources, to elicit and nurture the development of a future professional network, may be the most valuable outcome.

6.2. Communication

Before the workshop, communication between the A/UD and EE students was cause for some concern for the instructors because technical jargon can produce confusion and misunderstanding. However, communication did not cause any significant problems in either team. Both teams were able to overcome discrepancies and misinterpretation using the Internet and other visual materials.

Rather than relying on only verbal communication, students communicated through three-dimensional (3D) models, physical models, and sketches.

Communication at a personal level was significantly different between the two teams. Affected by the seniority, the dialogue in the SDC team between the students was limited, especially between A/UD and EE. This resulted in one-way communication from the team leader to the teammates, and the undergraduate EE students held back from raising concerns or introducing personal opinions. In contrast, the SES team used English to communicate because most of the team was composed of international students. Everyone on the team was comfortable with communicating in English. Based on the interview, the SES team leader thought that communication in English helped each member to feel empowered and equally responsible for the team's outcome. However, in the case of the SDC team, the team leader felt that all team members became passive and relied on the team leader to delegate tasks to each member.

6.3. Design Process

The focus of the course was on the collaborative nature of the workshop between the two disciplines and to determine the possibility and potential of working together. During the design phase, several significant findings were revealed. These observations indicated fundamental differences between A/UD and EE, which should be acknowledged as opportunities rather than threats for the two disciplines to forge a symbiotic working relationship.

The findings were summarized into the following categories: work scope, code and regulation, specificity vs. ubiquity, and innovation vs. innovativeness.

6.3.1. Work Scope

The workshop revealed a significant division between A/UD and EE students' participation. Understandably, during the problem scoping stage (problem definition and gathering information), A/UD students' contribution far exceeded that of EE students. Then, as the teams moved into the developing alternative solutions stage (generating alternate solutions and evaluation/selection), a significant contribution from EE students was observed. Even though each team met weekly, as the project was entering the solution development phase, A/UD students could not participate in the development of the design. This division of roles and workflow reflects how urban infrastructure is often designed and executed. However, if the aim of the inter-disciplinary workshop is to help students to imagine the future of cities, there are two options: (1) streamlining the process between project scoping and developing solutions or (2) restructuring the workshop so that all participants can contribute in every phase.

The first choice seems practical under the condition that the workshop expects to develop an innovative device. However, should the aim of the interdisciplinary workshop be encouraging the students to question and rethink the current state of city building or promote collaboration between the students? In terms of integration between the two disciplines, the second option seems to address the aim of imparting connective knowledge through inter-disciplinary collaboration. To provide such a scenario, the design workshop must be focused on design of the process so that A/UD and EE students can engage in a constructive and productive dialogue about cities?

Based on the interviews, the exchange of knowledge was uneven. EE students learned more about urban issues and the interconnected nature of the urban environment than A/UD students learnt about Arduino and other technologies. However, in terms of about-knowledge, students from both majors acquired hands-on experience of working and learning about the other discipline.

6.3.2. Specificity vs. Ubiquity

As shown in Figure 13, architectural design requires stages of design refinements with increased levels of detail as the design reaches construction detail level. As the Royal Institute of British Architects (RIBA) Plan of Work Stages indicates [49], each phase takes variables and clashes from range of scales.

This process helps architects and urban designers to pay attention to the surrounding buildings and to the site. Ultimately, architectural design process is streamlined to produce a customized and unique solution to a given site which is at the core of studio-based learning.

Figure 13. Royal Institute of British Architects (RIBA) plan of work stages, Dronkelaar et al. [49].

As shown in Figure 14, NASA's engineering design process (EDP) follows similar stages to RIBA plan of work stages; however, EDP tends to focus on the production of prototypes. Refinement through the reiterative process ensures the improvement of solutions [50]. The design workshop revealed a profound difference in design process and expected results from the two disciplines. This discrepancy requires a lengthy discussion as this discussion is integral to defining the ultimate goal and objective of the design workshop.

Figure 14. NASA engineering design process (EDP), NASA [50].

The workshop provided the EE students with a chance to work with a real site and to see the problem first-hand. This helped the EE students to visualize the compatibility and applicability to the site when designing a solution. Sites should maintain their uniqueness; thus, site-specificity is essential. Can engineers design solutions that are more authentic and localized? Architects are not trained to design ubiquitous buildings. By providing efficient modular solutions, architects may be able to provide cheaper and practical solutions. Perhaps, this is where the two disciplines can work together.

6.3.3. Code and Regulation

Another unique and critical design activity that was identified was checking the design solution against relevant ‘legislative framework’ Figure 12. For architects, at every stage, a different set of regulations and codes must be reviewed and applied to the design, i.e., urban planning regulations, zoning, building code, etc. [49]. And often, legal constraints pose the greatest limitations on implementation of urban interventions. A/UD students are trained to continually check the validity and compliance with the existing regulations at several levels. However, for EE students, compliances with safety regulations occur much later in the design process [50]. Throughout the workshop, most discussions and ‘learning’ between A/UD and EE took place were when EE students proposed ideas that required the overhauling of the current codes and regulations, and A/UD students had to explain why such idea does not work. SCs will require many updates and introduction of new legislations regarding smart environments.

6.3.4. Innovation vs. Innovativeness

The workshop offered a unique opportunity for A/UD and EE students to work together to produce innovative prototypes which were very different from the usual final products from architectural studio-based design workshop. Although the prototypes by the two teams demonstrated some degree of innovation, the outcomes do not represent the aspirations and complexity of the SC concept. On this note, a fundamental question to the nature of this experiment may arise: should HESD aim to educate the students to produce innovative products? Or should HESD try to impart innovativeness so that they can grow and mature as innovative professionals? For the premise of the ongoing research and at the level of HEI, the latter question seems appropriate.

7. Inter-Personal Competence Test

To verify if the interdisciplinary design workshop actually imparted skills and the capacity to address issues and goals of sustainable development, the inter-personal competencies of the five key competencies for sustainable development developed by Wiek et al. (2011) were used to evaluate each team’s performance based on unstructured interviews and course evaluations (Table 2).

Table 2. Summary of key findings and improvements.

Capacities in Inter-Personal Competence	Team		Insights
	Safety Every Step	Smart Drainage Cover	
1. Communication	English spoken due to int’l students, communicated weekly and outside classroom	Korean spoke with polite form used due to age difference among students, team failed to communicate weekly	Having int’l students or use of English can overcome hierarchical social structure between students
2. Deliberation and Negotiation	From problem definition through prototyping, productive and constructive negotiations occurred amongst the team	Insightful problem definition by Arch/UD, negotiations failed at every phase, Arch/UD and EE students kept distance, prototype failed to function	Conflict between two disciplines must be addressed early on and TA or instructors intervention to help with negotiation is required
3. Collaboration	Excellent collaboration throughout the process, voluntary video-making proves good team chemistry	Collaboration never occurred, divided tasks between Arch/UD and EE	Informal and voluntary collaboration set the tone for collaboration
4. Leadership	TA took on the role as team leader, their experience in Arduino earned the trust of the team early on, horizontal structure reinforced	The most senior students took responsibility as project managers leading to one-way/top-down communication and collaboration	Experience and knowledge of the leader matters, crucial to gain trust from the team members early on
5. Pluralistic and Trans-Cultural Thinking	Multi-national team, application of CEPTED, and concept of private and public property	Ran into problems in resolving the mechanical engineering problem, failed to share ideas and solutions	Learning original concepts from other disciplines energize
6. Empathy	Street safety and victims of crime provided a motive for the project	Problem definition failed to resonate with EE students	Problem definition to internalization of the problem stimulate empathy and participation

Despite the failure to produce a functioning prototype, both teams acknowledged the value and transformative learning experience from the interdisciplinary design workshop. In particular, the team leader of the smart drainage team regrets how the workshop turned out despite their best efforts to rectify the situation. In the future, I aim to prepare a systematic evaluation of the outcomes and coding from the voice recordings from design workshop interactions to supply structured data for empirical analysis.

8. Conclusions

Rather than understanding SCs as a threat to the traditional city-making disciplines, this paper proposes that it can be considered as an opportunity to expand and transcend the current state of sustainable development education for university students majoring in architecture and urban design. As demonstrated, the interdisciplinarity of sustainable education is a critical component in increasing the innovation and sustainable competence of students at HEIs.

The main body of the ongoing research will continue with the aim of providing an alternative method to design a transformative learning platform using SCs as a contextual framework to gather distant knowledge and distant disciplines together to collaborate at any given point in the students' life-cycles. Through building on the ideas of connective knowledge, this paper provides insight from the initial test of an interdisciplinary design workshop between A/UD students and EE students. Although a direct comparison between SD and SC was intentionally avoided, from the interdisciplinarity viewpoint, many similarities and opportunities surfaced: innovation through collaboration, sustainability through experience interaction, and knowledge production through increased individual capacity to collaborate. The ultimate goal of this research is to find an effective method to educate and prepare A/UD university students to expect and anticipate any opportunity to participate or lead transdisciplinary collaboration and research to bring real innovation to sustainable development and smart sustainable cities.

A follow-up workshop between A/UD students and EE students will use a number of parameters to produce data to allow us to perform an empirical analysis to improve and develop the design workshop further. Armed with empirical data, the research aims to expand the interdisciplinary collaboration with other technology-based disciplines as outlined by the SC concept as well as soft infrastructure disciplines such as public administration and social innovation. The interdisciplinary design workshop will be continually updated and improved to empower students with inter-personal competence to navigate and realize the future of sustainable urban development.

Funding: KRW 2,000,000 from Korea University Innovation Center.

Acknowledgments: Thank you to Beelee Chua, Department of Electrical Engineering, Korea University, and all the students who participated: Team 1 (Son Yang Bae, Kim Tae Ho, Lee Sang Ho, Song Yoo Soo, Nam Keum Ho, Kim Seung, Jang Son Young, Hwant Gyo Hyun, Yoo Sang Hwang), and Team 2 (Lee Dong Hyun, Michelle Narok, Zou Yunhao, Liu Yi Jun, Gu Xiaoxi, Liangyuan). Also, thanks to Korea University's Leaders INdustry-university Cooperation (LINC) program for support and assistance.

Conflicts of Interest: The authors declare no conflict of interest.

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