A Multi-institution Design Project on Sustainable Cities: The Sustainability and Social Entrepreneurship Fellowship

Mr. Christopher Rennick, University of Waterloo

Mr. Christopher Rennick received his B.A.Sc., Honours Electrical Engineering in 2007 and his M.A.Sc. in Electrical Engineering in 2009, both from the University of Windsor, in Windsor, Ontario, Canada. Chris is the Engineering Educational Developer in the Pearl Sullivan Engineering Ideas Clinic at the University of Waterloo, where he focuses on implementing hands-on, real-world design experiences across Waterloo's engineering programs. Chris is currently a PhD candidate in Management Sciences and Engineering at the University of Waterloo investigating student acquisition of design skills and knowledge.

Dr. Nadine Ibrahim, University of Waterloo

Nadine Ibrahim is a civil engineer who is passionate about the sustainability of global cities. She is currently the Turkstra Chair in Urban Engineering at the University of Waterloo. She is a triple graduate of the University of Toronto, and holds a BASc

Prof. Gordon Krauss, Harvey Mudd College

A Multi-institution Design Project on Sustainable Cities: The Sustainability and Social Entrepreneurship Fellowship

Abstract

This paper describes a pilot implementation of a multi-week, multi-institution design project with a focus on sustainable design of urban environments. Cities are home to more than half of the world's population, and account for 70% of greenhouse gas emissions globally, and that is expected to grow rapidly over the coming decades. In the Canadian context, this coincides with a severe national housing shortage; it is estimated that there is a housing gap of 3.5 million homes needed by 2030 that are not currently scheduled to be built. Despite cities' large environmental impact, they are also the economic drivers of the global economy. This staggering environmental and economic impact prompts us to reimagine our future cities. The problem of urban design is also inherently interdisciplinary, and human-centered, providing a rich environment for students to learn and develop their skills in sustainable design.

As we work to solve some of the world's most "wicked" problems, we understand that new models of collaboration must be implemented. It is with this interdisciplinary thinking in mind that a collaborative pilot project was launched by two institutions: one Canadian, and one American, in 2023. The Sustainability and Social Entrepreneurship Fellowship project brought together nine 3rd year engineering students from around the world to participate in a nine-week, paid internship project to work on multiple sustainability projects. By inviting an international team (whose costs are paid by their home institution) we brought together individuals from different cultural, educational, and engineering discipline backgrounds.

The students were tasked with developing solutions to assist the City of London, Ontario with meeting its housing pledge to the Province of Ontario to build 47,000 units by 2031. The student teams had access to a community of practice comprising of professors from the collaborating schools, as well as staff from the City of London, for help with subject matter.

The nine-week program was divided into several phases to guide the students through the design process. The first four weeks guided the students through information gathering and problem definition phases, ending week four with the students organizing into three teams of three students with their problem statement that they would pursue over the remaining time in the SSEF. During weeks 5-8, the student groups worked on solutions which address their specific problem statement, each with guidance from a faculty mentor. In the final week, the students presented their work to the City of London and at the host university.

This paper will present an overview of the program, key takeaways and lessons learned from the organizers, as well as thoughts from the student participants. Each student took part in an exit interview in the final week of the program with one of the organizers; these data will form the foundation for the evaluation of this initiative. The program overall was a success, however the student feedback identified several areas of improvement for future offerings.

1 Introduction

The modern urbanization surge has placed cities at the forefront of global challenges, with more than half of the world's population now living in urban areas. These urban areas contribute approximately 70% of the planet's greenhouse gas emissions [1]. This growth presents a paradox as cities are crucial for economic development and growth yet significantly negatively impact the environment. Related to this issue, Canada faces a severe housing crisis, requiring an additional 3.5 million homes by 2030 to meet anticipated demand [2]. This goal far exceeds the current rate of new construction. This situation highlights the urgent need for innovative solutions that balance economic growth, societal benefits, and environmental sustainability.

In response to these complex and interrelated challenges, The Sustainability and Social Entrepreneurship (SSEF), a collaborative effort between the University of Waterloo in Canada and Harvey Mudd College in the United States, launched its inaugural iteration in the summer of 2023. The SSEF aims to foster innovative, human-centered, and sustainable urban design solutions through interdisciplinary international collaboration. The SSEF reflects an understanding of the multifaceted nature of urban problems and seeks to bring together diverse perspectives and expertise to address these issues.

The program was structured as a multi-week, multi-institutional pilot that brought together nine exceptional third-year engineering students from five countries and five institutions. These students engaged in a nine-week internship focused on developing sustainable urban futures. They were specifically charged with addressing London, Ontario's housing shortage in line with provincial objectives. Their mission was to devise actionable, sustainable solutions to facilitate the construction of 47,000 housing units by 2031. This challenge required innovative thinking using entrepreneurial, design thinking and systems engineering approaches and a commitment to sustainability and social responsibility.

The SSEF distinguishes itself from similar programs in great part through emphasizing international collaboration, development of cultural competence, and a focus on social entrepreneurship. The program works as a fellowship rather than an academic course and participants did not receive academic credit. The SSEF shares similarities with programs like MIT's entrepreneurial incubator, The Engine [3], Harvey Mudd College's Clinic engineering professional practice program [4], and Purdue's EPICS community engagement focused program [5]. However, SSEF is distinct from these programs in how it prioritizes environmental sustainability and societal impact with respect to more traditional financially focused entrepreneurship activities and industry-academic partnerships. This international and multidisciplinary approach aims to cultivate a broader perspective among participants, leveraging the diversity of their engineering training, enhancing their ability to contribute to sustainable urban design solutions.

The SSEF incorporated a robust evaluation framework to support continuous learning and improvement. Through exit interviews with student participants, the program gathered insights into their experiences, learnings, and recommendations, offering valuable feedback for future iterations. The inaugural Sustainability and Social Entrepreneurship Fellowship serves as a prototype for interdisciplinary, sustainable urban design education, emphasizing the importance of cross-cultural collaboration and innovation in addressing the pressing challenges of

urbanization and housing shortages. It is hoped that those interested in extrapolation of the activities and learnings of the SSEF for similar programs to address other pressing sustainability and societal needs in different locations and contexts will benefit from this description.

1.1 Motivation

Engineering curricula evolved over half a century ago and have not changed much during this time. On the other hand, incoming students who want to become engineers of the future have changed dramatically. The new generation of students come with a keen desire to change the world and make it a better place with regards to diversity, climate, environment, accessibility, sustainability, etc. [6] These are indeed big problems that require a fresh way of teaching and training engineering students.

As engineering students transition into professional practice, many of the problems they will be faced with are so-called "wicked problems". These problems are challenging to solve because our understanding of them is incomplete, evolves rapidly, and is frequently contradictory. These problems are socially complex, and transdisciplinary in nature; they cannot be solved by focusing on only the engineering perspective [7]. To understand these problems and have a chance to solve them the students must:

- feel comfortable in dealing with other disciplines,
- be ready and open to learn new concepts either themselves or with the help of others,
- be able to state their point of view and must be able to accept others point of view,
- be able to rationalize, handle ambiguity, deal with uncertainty and work in transdisciplinary teams.

Recently, the Faculty of Engineering at the University of Waterloo established the Pearl Sullivan Engineering IDEAs Clinic (Ideas Clinic), to build capability among our students to deal with ambiguity, and uncertainty while learning to solve real world problems. While the Ideas Clinic has previously focused on the creation and implementation of curricular activities, introducing curricular innovations can be met with institutional resistance. Recently, the Ideas Clinic has begun pursuing co-curricular programming to supplement its previous work. In this setting, it is much easier to be nimble, and adapt instruction to meet student and societal needs. Furthermore, co-curricular activities can be run in an environment free from academic stresses, that is conducive for student motivation and long-term learning.

When envisioning the Sustainability and Social Entrepreneurship Fellowship program, the organizers decided that students should be given a real-world problem where they can apply principles of sustainability to solving a pressing societal problem. Sustainability is an important concern for every engineering problem and thus has many dimensions. Sustainability requires reflecting on all effects and impacts the engineering solution will have on society, the environment, and project economics. The multi-faceted nature of sustainability requires that the engineer be aware of these facets and ways of addressing them. Teaching the many facets of sustainability is a challenging task.

Introducing the multi-disciplinary challenges relating to sustainable design in a curricular setting is challenging and does not match real engineering practice. Students working on curricular

projects have similar academic training and approaches to problem solving. This differs from a real-world scenario where the engineers within the team come from different engineering domains and with different training. For replicating the real-world scenario, a team of students from different universities from around the world could be used. This complicates the logistics but makes for a better real-world scenario. Additionally, typical problems in engineering curricula are short in duration. Assignment problems take only a few minutes and give limited exposure to the subject. Even course projects are limited to students spending about 20 to 30 hours on one problem. Spending quality time on a problem is linked with deep learning and classical assignments and projects are limited from that perspective. To ensure deep learning a longer exposure to a problem is preferred.

For students to be successful working on important sustainability problems, they require both a depth of engineering knowledge, and also a breadth of knowledge and experiences relating to sustainability and the approaches to sustainable design. Recognizing that a collection of students from different engineering programs and different universities will have different levels of understanding of these topics, the organizers of the SSEF program sought to create a community of practice of expert faculty and experts from industry who could give expert talks and who could assist students in attaining the knowledge. Lastly, the SSEF program would need an engineering domain that students find interesting, and which they could personally relate to. Ideally this would be one where a global perspective on the challenges of the domain would add richness to the discussion, and which was broad enough for students to identify specific problems. The selected domain would require a large concentration of experts and available data for the participants to make intelligent decisions. The chosen domain was the design of urban environments.

1.2 Problem Space

Prompted by a desire to introduce open-ended sustainability problems to students using real-world experiences in an immersive learning environment, the challenge was three-fold: identifying a problem domain, locating a real challenge that include stakeholders that could be consulted to inform the design process, and develop an experiential learning experience that engages students with the problem beyond the classroom. The organizers found an opportunity in urban challenges that are multi-faceted in nature, involving stakeholders who run the city, and can be addressed meaningfully through a sustainability lens to create a comprehensive solution and recommendation. The organizers leveraged the support and expertise of the Douglas Wright Engineer-in-Residence (EIR) at the University of Waterloo, which is a role that creates an avenue for mutually beneficial engagement between the academic community and the engineering practice community. It is grounded in educational collaboration with the practice community, where the EIR is selected to foster and develop industry-academic engagements as they promote leadership among engineering students for the betterment of our cities now and into the future. The Douglas Wright Engineer-in-Residence aligns with the vision for urban engineering by offering expertise in a variety of contexts including leadership, mentorship, technical guidance, in addition to teaching support, and other roles that leverage specific skills of the EIR [8].

In light of Bill 23 by Municipal Affairs and Housing in Ontario in response to the Canadian housing crisis, the bill was intended as a way to help the province achieve its goal of building 1.5 million homes in 10 years (Note: Bill 23 was later revoked in part due to the controversy around

this bill and where the forecasted growth will take place that goes against sustainability goals) [9]. The Engineer-in-Residence for 2023 (Kelly Scherr) was from the City of London, Ontario where she holds the title of Deputy City Manager for Environment and Infrastructure and has access to many engineers and a wealth of data related to design of services in the city that they were willing to share. The students were tasked with developing solutions to assist the City of London, Ontario with meeting its housing pledge. What this meant for the City of London translates into London's Housing Pledge to identify actions and strategies to create a path for development and building community to build 47,000 units by 2031 [10]. The challenge was framed as: How can the City of London develop infrastructure that is sustainable and kind? This is a wicked challenge as it requires thoughtful integration of engineering systems with social and environmental sustainability perspectives. From the engineering perspective alone, the urban environment is a "system of systems" including transportation, water, sewage, electricity and many other systems/services. So, it was decided that the goal of building a sustainable growth plan for expanding the City of London by adding 47,000 homes would provide students with a rich domain from which to find suitable problems that they are interested in solving.

The nine participating students came from the University of Waterloo, Harvey Mudd College, Khalifa University, the University of Prince Edward Island, and Tecnologico de Monterrey. Throughout the SSEF, the students had access to a community of practice comprising of professors from the collaborating schools, as well as staff from the City of London for support, guidance and data inputs. Additionally, the students leveraged their lived experience from the cities that they come from and created meaningful comparisons to identify the value of context in design solutions. The students self-organized into three groups of three students, bringing in their experience in their respective engineering disciplines, and their interests in sustainability topics to address the challenges. The three chosen project topics were:

- Growing & Greening: Enriching the City of London Using Rooftop Gardens
- Transit & Living for a Kind and Sustainable London
- Sustainable Development in London Using Local Climate Zones

The sustainability plans were developed as recommendations to the City of London and were presented to the Directors in the Environment and Infrastructure Division, and Acting Mayor of the City of London. The learning experience demonstrated an opportunity for knowledge sharing, engagement with stakeholders, mentorship by experts, collaboration in team environments, transdisciplinary thinking and sustainability mindset, and creativity in the design process.

2 Program Overview

The SSEF program ran from June 5 to August 4, 2023, and included 4, approximately 2-week phases which correspond to the double-diamond design process: Discover, Define, Develop, and Deliver [11]. The program featured lectures and field trips to teach important content to the participants, generally along 4 themes: design, sustainability, urban engineering, and systems modeling. These lectures were front-loaded in the program; weeks 1, 2, and 4 had 8 lectures delivered by program leaders and/or guest lecturers, while week 3 had a series of field trips to learn about municipal infrastructure in 3 different Ontario municipalities. At the end of week 4, the students selected their teams and project topics for the remainder of the program. Week 5 had

2 guest lectures, but generally weeks 5 to 8 shifted the program to a supportive mentoring environment as the participants researched their selected problems and developed their proposed solutions. In week 9, the participants presented a 20-minute overview of their projects to stakeholders in the City of London, and at the University of Waterloo, and delivered an overview poster and 3-minute pitch video summarizing their ideas.

Each week, the participants spent 3 hours on Wednesday morning with Kelly Scherr from the City of London. In the first half of the program, Kelly presented an overview of a municipal infrastructure topic each week; in the second half, this time was used by the participants to collect feedback on their projects from an expert. A detailed overview of the program structure is in Table 1 below.

Table 1 Weekly lecture content and deliverables

	Lectures	Lecture themes	Deliverables
Week 1 June 5	Introduction, design expertise, climate change, sustainable cities, user needs and requirements, life cycle assessment and energy	Sustainability, design, urban engineering	End of week reflection
Week 2 June 12	Sustainability, climate modeling in Matlab (2 lectures), municipal governance, renewable energy and energy efficiency, Bill 23, work in the public sector, climate change	Sustainability, urban engineering, systems modeling	End of week reflection, research presentation
Week 3 June 19	Field trips: London wastewater treatment and water supply, Toronto transportation and energy, University of Waterloo solid waste management	Sustainability, urban engineering	End of week reflection
Week 4 June 26	Sustainable building science, intergovernmental panel on climate change, urban farming, mind mapping	Sustainability, urban engineering, design	End of week reflection, project topic and team membership
Week 5 July 3	Agent-based modeling, sustainability economics	Sustainability, design, systems modeling	End of week reflection
Week 6 July 10	Team health, communicating municipal construction to project stakeholders	Urban engineering	End of week reflection, team health assessment
Week 7 July 17			End of week reflection, mid-project presentations
Week 8 July 24			End of week reflection, 20-min presentation draft, poster
Week 9 July 31			End of week reflection, 3-min pitch video, exit interview

2.1 Participant Deliverables

Structured deliverables for student participants were kept intentionally light throughout the 9-week program; allowing the organizers to stay flexible and follow the needs of the students. An overview of the deliverables and their timing is given in Table 1 above and will be expanded on further in this section.

A template for the weekly reflections was provided to participants at the start of the SSEF. This one-page template summarized 3 models for learning and/or reflection including Kolb's learning cycle, Gibbs' reflective cycle, and Schon's reflection-in-action and reflection-on-action concepts. Following these, a series of prompts, adapted from the What? So What? Now What? framework [12] led students to think through their experiences for the week: talks they heard, research they conducted, and other experiences. For each of these three categories, students were asked to summarize concepts that stood out to them, as well as a prompt to think about how the experience changed their thinking about the problem they are trying to solve. The template ended with a forward-looking component, asking participants to think about what they are still unsure of, and to complete some rough planning to steer the work in the subsequent week. These reflections were completed on Friday afternoons each week, and each participant uploaded them to a private channel on Microsoft Teams, which was the platform of choice to organize all the work that took place in the SSEF program.

In week 2, to supplement the presentations from the invited speakers, each student was asked to prepare a 10-minute research presentation on a topic of their choosing. The participants picked a diverse range of topics including housing and homelessness, bike infrastructure in Amsterdam, wildfires, and a deep dive into Ontario's Bill 23.

The next deliverable was to decide on project teams and topics at the end of week 4. One of the program organizers joined the 9 participants for a day-long, facilitated discussion of potential project topics. Ultimately the participants split into 3 teams based on mutual interest in a project topic. The three topics were: investigating the impacts of urban greenspace on water retention and heat islands, retrofitting existing construction with green roofs for improved water retention and insulation, and sustainable transit solutions including bike infrastructure. Once the project topics were selected, the subsequent weeks had few structured presentations, instead shifting to a mentorship model with each team as they researched and delivered their projects. After the participants had worked together for a couple of weeks, a team health assessment workshop was conducted with each team. This seeks to highlight the strengths and areas for improvement in team processes. In week 7, each group prepared and presented an initial version of their 20-minute project presentation to the program organizers for feedback. This checkpoint was an opportunity to provide formative feedback on their work to date, as well as their presentation itself.

The final project deliverables were all due at the end of week 8/beginning of week 9. These included a poster overview of their project, a 20-minute presentation for project stakeholders in London and at the University of Waterloo, and a 3-minute pitch presentation. The poster and 20-minute presentation were delivered to City of London staff at the start of week 9, and again to University of Waterloo stakeholders on Wednesday of that week. The rest of the time that week was spent on preparing the 3-minute pitch presentation, and on wrapping up the program

including the exit interviews between each participant and the organizers for their thoughts and feedback on the program. These final deliverables intentionally did not include a written report as the organizers felt the participants would not have the time required to complete high-quality reports; especially as some of the international participants were non-native English speakers.

3 Results

During the final week of the SSEF program, one-on-one exit interviews were conducted between one of the organizers and each of the participating students. These data were originally collected for continuous improvement of the initiative, however secondary use of these data was subsequently approved by the institutional ethics board for research purposes (Office of Research Ethics #45798). Of the 9 total participants, 7 provided consent to include their interview transcripts in any published research, with at least one participant providing consent from each participating institution. These interviews were semi-structured and were between 25 and 45 minutes long. The 7 transcripts were verified for accuracy and de-identified before analysis began. The quotes that have been reproduced in this paper have been lightly edited for clarity.

3.1 Feedback on Teaching Content

Participants generally had very positive feedback about the lecture content in the first four weeks of the SSEF program, with some talks like the presentations on the Intergovernmental Panel on Climate Change, and the presentation on urban farming being standouts for many of the participants. Even beyond the lectures, the students generally reflected positively on their learning while in the SSEF program.

> *P1: "Ohh yeah, very useful. Like so much information that is now in my head. And I'm like, wow… I never thought I would learn about green roofs and… so much even about Canada… Yeah, so much information that will stay with me."*

> *P2: "I think it surpassed [my expectations] like we have really, really, really good teachers along the way. It was really enriching that experience. We have a ton of different perspectives, ton of different views that cover different dimension of human life and engineering and science… It was great."*

Some of the students did comment that there were talks that ultimately did not relate to their chosen projects, and so were ultimately not relevant to their specific project. The participants also mentioned that some of the talks felt like they were delivered at inopportune times during the project; either too early or too late.

> *P3: "certainly there was none that I was like, wow, this is a waste of my time, get me out of here. [One design topic] was like interesting, but it felt like a first week kind of thing, like it would have been better if we had done that like from the start and not week four or five or whatever."*

During the interview, the students were asked about their challenges during the SSEF, in particular the pace of activities, and timing of deliverables. In the first 4 weeks, the students had different experiences with the pace. Some found it too slow, while some found the amount of information overwhelming. As with any lecture delivery, students will have different perceptions on the pace of the lecture, but since the SSEF was less structured than a typical engineering

academic semester, it is important to have other activities for participants to work on that can fill the time for those who may find the pace too slow.

> *P1: "Honestly, I felt like it was a little bit too slow, having only two talks per day. Yeah, I had a lot of free time and also I didn't know, like, OK, what are we doing next? I only did some research… after the talks. But then… it was like, so when are we gonna do the project? I feel like you could have squeezed in like an extra talk, maybe."*

On the field trips, most students found them interesting; but they were planned specifically for a week when most of the organizers were away at a conference. This meant that program organizers were not present during the field trips, and instead relied on a grad student and the local hosts at the field trip location to explain what was happening. For at least one student, this may have led to challenges in understanding what they were meant to take away from the field trip visits.

> *P4: "I had a fun time on the field trips. It was cool to see things, but coming from a mech background like particularly the water treatment ones I was like, I don't even know what I'm supposed to be looking at realy. I'm kind of just wandering around looking at things without really knowing it's significance or what anything's supposed to mean."*

During the interview, the students were asked what skills or knowledge they gained through the SSEF program. The students mentioned a mix of technical and professional skills, though professional skills were mentioned more frequently by all the students: six of the seven students mentioned teamwork, and four mentioned communication skills (with two explicitly mentioning oral presentation skills). Among the other skills mentioned were research skills, software skills (like Matlab), modelling, skills relating to mapping, self-management, and handling uncertainty. One student spoke about developing empathy for people from another culture:

> *P2: "I I have to come in here without thinking too much about the Mexican background, about our problems, of what do we think is important. And it's not like some of these things are going to be really different from here… I think that that was something that I had to develop like… that empathy without um looking too much into my background and use the useful, the helpful things from my background to apply to it."*

Another spoke about developing the ability to communicate and work with people from other cultures:

> *P5: "So it was really cool for me to kind of learn how to work with people of different backgrounds and just like better communication and how to express the ideas I was saying in a way that wasn't… You're not dumbing it down… There's just a language barrier, so you have to articulate yourself differently."*

For some of the international students who did not speak english as a first language, they appreciated the opportunities to practice their presentation skills:

P6: "I think a big skill [I learned] is still like first stand in front of… important people of the City of London, like to really be clear in what your message is going to be. Like public speaking. It's a big challenge and also work [in a] team because you're working with people you don't know and they are from different cultures… [and] some of us don't speak English, as a native language. It was really good to do like a work project."

Summarizing her experiences, one of the students commented that the relative lack of structure of the SSEF allowed her to focus her efforts on learning skills that were interesting or important to her own development:

P4: "you're going to get out of it what you put into it. You can sort of target what you wanna get out of it. Could be something that you know you're interested in, you can find a way to put that into a project… if you wanna like learn modeling… there are ways to do that through a lens of a sustainability problem."

3.2 Feedback on Deliverables

When asked about the weekly reflections, most students found them most useful in the initial 4 or 5 weeks of the project while they were in "learning mode", but they were less useful during the weeks where they were working on their projects. One student commented on how busy they were trying to finish their project that they did not complete reflections in the later weeks:

P4: "I feel like they were useful in the beginning and uh, and then I feel like the usefulness kind of fell off a little bit… [Near the end of the project] we didn't really have the same 'reflection kind of mindset.' And it was like, no, every single day is for grinding for the project."

Interviewer:"you weren't doing them towards the end. You were just in doing, not in reflecting."

P4: " Yeah, like there wasn't, there wasn't time to reflect . A bunch of us kind of forgot to do them towards the end"

The students also commented that the reflections might have been more useful in the second half if the required template were different to match the different nature of the work at that phase in the project.

On the team health assessment that was completed in week 6, two of the groups found the information interesting, but they didn't perceive any struggles with their team, and so the exercise had a limited impact on their project. The third group, however, had a different experience, with one student commenting how it helped their team processes:

P1: "that was really helpful… with my group, we had a little bit of communication issues, but then after that we were like, OK, let's fix this… Like how about 10 minutes at the end of your day, we have like 10 minutes where we say everything that we weren't able to say during the whole day and like what is our plan for tomorrow."

The final deliverables included a 20-minute presentation to London city staff, a poster, and a 3-minute pitch video. When asked how they felt about the final deliverables, most appreciated that

they didn't have to write a report, and they generally found that they were able to fully communicate their efforts and ideas in these formats. One student commented:

> *P4: "Umm, I think like the poster and the presentation was good to work on and good mediums to communicate like certain aspects of our work. I think the pitch video [was] a little bit less useful, but we were also kind of rushing it…. [it] was a little bit less useful for us personally, but if it's something that's helpful, like grow and over time like what all the groups have done year to year, I can see that. Umm, but I think, yeah, I feel like it covered A lot of what we wanted to say between the three."*

This same student went on to comment that their biggest consideration was that they wanted the material they produced to be useful to the staff in the city of London. All the groups had extra material if London had asked for it, but this group produced a more detailed report that is now being submitted as a research paper:

> *P4: "Like we're going to end up doing it anyways, like having something written would have been nice if there was like a certain level of detail that like is not appropriate detail to put in a 20 minute presentation but would be relevant information for somebody to have were they to actually want to understand our project fully."*

3.3 Feedback on program structure

When asked about the program structure, several of the students mentioned that they experience an uncomfortable amount of uncertainty, especially in the early weeks as they adjusted to the demands of the program, the new environment, and began to understand the expected outputs. The organizers were generally only releasing the schedule of talks one week in advance, and so the added uncertainty of their detailed schedules for the week was also uncomfortable for the students. One student discussed these feelings during their interview:

> *P1: "Umm, I think just like the confusion in the beginning… it was like, every week we would know what the plan was during the week. So I was like, OK, maybe if I had a little bit more clarity like that would have been great umm, yeah… and then like in the middle of the program where like we had to start looking at the problem in our project, I was a little bit like do we actually have enough time to work on it? I was like damn, we don't have enough time But like we like, just kept going."*

Some of the students were better prepared for dealing with these uncertainties than others due to the nature of their home programs. One student described the design sprints that are common in their home institution:

> *P2: "I mean, I have no problem working with this, it's just that ambiguity doesn't do well sometimes… the workflow… was alright because our entire college system is that way.*
> *We have five week courses at a time, and we work with professionals, with industry, and they throw us a problem, we have to solve it and present it in that five weeks and we have actually nine weeks of this. So it was actually more time… We're used to that*

kind of stress. Uh, the the other people in the program I think don't connect with that."

Most of the students also felt a significant amount of pressure from the time constraints on the program. Group and project selections happened in week 4, leaving only 4 weeks to research and develop their projects. For most, this felt like not enough time, and so they began feeling anxiety around the deadlines leading up to the project selection day:

P3: "I guess during around the four week point I got a little bit stressed… Anxious to get something kind of done… something to present. And it felt like we hadn't really… even started on it. So like I think and for the sake of like having more time, I think … it would have been more helpful if we'd started earlier on projects

Interestingly, even though most felt anxious about completing the projects in the time allotted, when interviewed at the end of the program, most of the participants felt that 9 weeks was enough time for the SSEF. The most common feedback from the students was to move the project and group selection earlier in the program so that expert talks could be arranged that directly apply to their selected topic area(s) and/or to provide them more time for their projects.

P4: "Definitely, not. like did not have enough time for the most part. It was, like, mostly constant throughout, although kind of increasing the further it got. Like at the beginning it was like, oh my God, eight or nine weeks, that's going to be tight, but it's gonna be fine. And then coming back from field trips and then not to pick the projects until the end of that week… or something, and kept getting more and more like, oh my God, there's only like 5 weeks left, only four weeks left... so it's like, yeah, always feeling that you didn't have enough time."

One of the students would have enjoyed more time to engage in this work. With more time, they felt they could have better connected to the local context of London, and conducted more research:

P1: "I think, yeah. More time. Yeah, maybe even like 3 months or four months, because… if we had more time looking at the problem, maybe we would have found things that we haven't found about London and we could have actually connected with the people in London and got some information from them like maybe the transportation department. And, yeah, made it like a little bit more specific."

The students were asked to comment on the challenge of the program during the interview and whether they had enough support to be successful. All the participants commented that the program was challenging, but that they had access to the supports they needed to work on their projects. One of the students spoke about how they had managed the challenge during the project:

P2: "it was challenging, of course it was challenging because a city is such a complicated system… So many things that you can, uh, look into: human life, food, energy, housing, transit, school, politics, behavior, wellness, healthcare. I mean such such a complicated system, and to try to narrow it down to an equation or a model or a solution was a little bit overwhelming from the get go I think. I would like to think that everyone on the program felt that way, but I mean, we found

areas of interest and we don't… we we're not solving climate change, but we're giving a little bit back to the people in there. So yeah, I mean you cannot do everything, but you can still do good."

Supporting the students with faculty mentors, and visiting experts was no doubt aided by the fact that University of Waterloo is a busy campus year-round because of the nature of the co-op program. One group was also proactive in seeking out expertise outside of the SSEF organizers. They connected with experts both internal to University of Waterloo, and Western University in London to improve their understanding of the problem. One of the members of this group commented:

P4: "I think we definitely had a lot of support there. [Our mentor] was really great and helping us where we needed it and then maybe like when I talked to the geospatial center at University of Waterloo… the person that we were in connection with there was very helpful. You're like, accessing supports on campus that I wasn't even like, really super aware of. Which was kind of interesting… I think there's definitely a good amount of support there."

In contrast, one of the groups had somewhat of a mismatch between their project topic and their faculty mentor. Their mentor was lacking the deep technical knowledge of the topic area, and the students felt this hampered their ability to understand their problem deeply. Fortunately, a lucky encounter with another faculty member at University of Waterloo gave them some direction that was helpful and helped highlight areas that they could look into. One of the group members described the situation:

P1: "She gave us so many resources and she even told us, like, you can do a simulation in this program and stuff. But, it would take a couple of weeks. So we were like ohh, if only we had this previously, someone who… you know can just give us so much knowledge and… yeah, that was great. So maybe once you've formed the groups you'd have like a week where they would learn more from people who have the knowledge about the topic"

3.4 Other feedback

Residence rooms with meal plans were reserved on campus for out of town students. This residence frequently has international students staying there for short duration stays (2-8 weeks), and so were a great support for messaging in advance of the students arriving. They also had opt-in trips on the weekends throughout the summer that the SSEF students could take advantage of. The living expenses for some students were paid for by their home institution, while some paid for their own way. This led to some students deviating from the planned residence: in one case, a student who was paying their own way was able to stay with a family member in town to save costs, and in another case, two students opted to stay in a different residence than originally planned. The students were aware of these inequities in their levels of support from their home institutions, and this was a sore spot for some of them when reflecting back at the end of the SSEF. These issues notwithstanding, the participants were able to build a strong sense of community with their fellow participants. One participant described the friends they'd made:

P3: "I had a lot of fun this summer like getting to know everyone. We did a bunch of like little trips and activities and I think it was just a really good, good group of people. And yeah, we've become really close over the time here. "

For the student who stayed in town with family, they felt a little disconnected from the other participants, but was still able to join some of the activities outside of the working hours with the others:

P6: "yeah like there were some activities that they were like in the afternoon that they did that I... couldn't go because like it was far [from where I was living]… we still got to hang out with each other even if it's far… I will recommend [it's] better to stay close to the university so you could like interact more"

One of the out of town students staying on campus was asked what their thoughts were on having a larger cohort of participants. Generally, they saw this as a positive:

P3: "I think it would have been nice to have more people, but also so it felt kind of small at times like because I think the people who are off campus were weren't really like as interested in like, hang out with us. So it ended up being like me and [two others], who are just really at [the residence], where we were able to do a lot of stuff together."

While the organizers worked to bring in expertise from outside of engineering to show the breadth of the problem space, once the students began on their projects, they may have benefitted from additional technical mentors from outside of engineering. The engineer in residence filled some of this need, nonetheless, one of the students commented:

P4: "it would have been nice to have… somebody in planning coming in if you were all like 'this sounds like a planning project', and none of us know anything about urban planning. So, I think that might have been another interesting lens to bring in if the future challenges are in any way kind of related to city development as well."

Aside from the project mentors, the students also commented that they need a clear program lead to direct questions during the program. For most of the 9 weeks, and in all of the leadup communications, there was a clear program lead, however that person had to travel for a conference in week 8 of the program, just as the work time really started to get busy. They also had their own work to do during the 9-week program, and so was not always available to field student questions. One of the students brought this up at the end of their interview:

P2: "sometimes it was hard with you [the lead contact] away. I mean, at least for me, as far as I'm concerned, you're the person directing this program and your being far was like, how do we… send a message?... but I mean, [other organizers] stepped in.. It's just that I think it would have been a little bit better if there was, like, I don't know, like you or someone like kind of permanent inside the same room as well as when we wanted to do, like, direct questions."

As a parting message, one of the students in their interview gave advice for future students taking part in this initiative. The following quote serves as an excellent overview of their experience in the SSEF program, as well as some general design wisdom:

P2: "Come with a fresh mindset.
Umm, your engineering background is going to help you, but also you're going to have to connect with your human dimensions.
You have to connect with environmental needs and you have to connect on how are you going to help into a situation, into a problem.
The best way without affecting other things and how to be a complete, integral, sustainable individual and a professional. Work In a self-managing way, be accountable for what you do, and what you don't know.
So man, what do I say to the next people coming to this program?
Just hoping to learn a lot, be more sensitive, allow yourself to be surprised, and sometimes the things you have to find the least interesting are the things that you're going to learn about the most and and don't think too much of how would this apply to your country's background.
You're going to be here and going to apply it to a different situation, to a different lifestyle, so don't doubt in your ideas.
Don't complicate it too much, do not fixate on an idea of a current problem.
Make sure that you have enough space in your mind and your heart to be creative, to break boundaries, to be disruptive… Do not limit yourself, and well, it's going to be a challenge to learn to ideate and to make it to real life and to communicate it…take advantage of everything here and maybe this will open up doors for you in here or somewhere else."

4 Discussion

Overall, the organizers view the pilot offering of the Fellowship program as a success. This paper did not discuss the integration of the engineer-in-residence in detail (that will be discussed in a future paper), but the working relationship with the engineer-in-residence and the City of London was very successful. This program provided a new way for the engineer-in-residence to have deep interactions with undergraduate students, and the presentations at the end of the fellowship provided some new perspectives for London city staff to investigate further. The initial vision was to include more students from more institutions, but while a group of 9 students is relatively modest in size, the smaller group enabled the organizers to learn along with the students how to offer a program of this nature. For many of the organizers, this program provided a means to think deeply about incorporating sustainability principles into their design practice and teaching, and forged connections to other experts at the host campus, and beyond.

The organizers of the SSEF program are all experienced design instructors, and so supporting the students as they worked on their projects was not all that different from supporting students in capstone design. Indeed, a number of the deliverable templates (e.g. the poster) were borrowed directly from capstone courses which the organizers teach. The most challenging aspect of the SSEF for the organizers was organization and coordination of the students and the overall program. Synchronizing the program to work for several different institutions was challenging. For most of the institutions, the winter academic semester was finished by mid-May, however one of the participating universities had exams running until the end of the second week of June. The students from this university had no choice but to join online in the first two weeks and so did not get the benefit of interacting with those presenters in person. This did not seem to impact their ability to make social connections with the other participants, but no doubt impacted their

level of understanding of the topics presented in the first two weeks (which was the most intensive period of content delivery). Similarly, one potential participating university who has a semester running until the end of June was not able to join the program at all due to the differences in the scheduling of their academic terms.

Coordinating the guest speakers also presented challenges. Most of the speakers were local connections at University of Waterloo, and as mentioned previously, summer is also a busy time at Waterloo as normal courses run year-round due to the co-op program. This meant that speakers were scheduled based around their availability first and foremost, and not necessarily when that talk would have the most impact on the SSEF program. As was evidenced in a number of the student comments, this meant some presentations felt out of sequence, and so their impact was perhaps lessened.

For the pilot offering, institutions were contacted using the organizers' social capital at other institutions. This factor, combined with the requirement that students were available from June to August to participate, plus the costs involved in travelling to Canada and staying for 9 weeks, meant that much of the world was not represented in the first group of participants. Future offerings of the SSEF will seek to include a more global pool of participants, but the organizers recognize that the costs involved in sending students may be prohibitive to certain institutions. Future efforts to find program sponsors will hopefully lessen this burden on the participating institutions and will improve accessibility to the program.

As this was a pilot offering of this program, the initial communication with participants in setting their expectations for the program could have been improved. The students had different understandings as to the working hours and level of effort that was expected of them. This seemed to arise from multiple causes: lack of clear expectations from program organizers, and differences in how they were identified, and how this experience was counted by their home institutions. For the local students, this experience counted as their summer co-op work term, and so the natural expectation for them was that this would be full-time, 35-hour per week work. For others, this was a paid summer job, while for others, they were paying their own way, and this experience did not have any official standing at their home institution. Wherever possible, the organizers pushed to have this experience "count" for something at their home institution, but not all participating universities had an easy mechanism to do that. These differences led to inequities among the students that seemed to be reflected most strongly in their work ethic during the first 4-6 weeks of the program. Having said that, these differences seemed to disappear once the project work began in earnest as their motivations shifted to delivering something useful to the city of London.

Reflecting on the design behaviours of the students, and their expressed anxieties at delaying the start of the project work until week 4, their experience matches closely to the novice design behaviours described by Crismond and Adams [13]. The students found it uncomfortable to think about the problem space, and desired to quickly move into work on the design project; behaviours that closely match the beginning strategies in "understanding the challenge" and "building knowledge" in the informed design and teaching learning matrix. The design of the program was intentionally constructed to slow down the students in the problem formulation stage; to get them to engage more deeply with understanding the problem space before selecting their problem. In hindsight, the students could have been better supported in dealing with their

discomfort in this stage and delaying until the end of week 4 may have left too little time to complete the work they wanted to on their project. It seems that many of the participants knew the direction they wanted to head in, so moving problem selection a week or two earlier, but continuing to help them research (including bringing in expert speakers that explicitly target their projects) before jumping to solutions may be a preferable way to model and practice expert behaviours with the students.

5 Conclusions

This paper described a 9-week, full-time, trans-disciplinary design program that brought nine students from five institutions together to propose solutions to the challenging problem of urban development that are both sustainable and kind to the local residents of London, Ontario. The program included explicit instruction from a diverse community of experts concentrated in the first 4 weeks, followed by 5 weeks of work on self-selected design projects in teams of three students each. The students completed projects on urban infill development using local climate zones, sustainable transportation infrastructure, and residential conversions of empty commercial buildings with green roofs as their projects, which were presented to staff from the City of London in the final week of the program.

Student feedback from the program was positive; students reported improving a broad set of technical and professional skills during the program – most notably teamwork and communication skills. Students also reported the SSEF program was useful for the learning, and for building a community with the fellow participants. Future offerings of the SSEF will seek to expand the number and diversity of participants, and minor adjustments to the overall program structure are expected to address student feedback from the pilot offering.

Acknowledgements

The authors would like to acknowledge Derek Rayside and Kumaraswamy Ponnambalam from the University of Waterloo, and Kelly Scherr and the staff from the City of London for their commitment and mentorship throughout the inaugural Fellowship. The authors would also like to acknowledge Grant McSorley, and Amy Hsiao at the University of PEI, David Antonio Buentello Montoya at Tecnologico de Monterrey, Karyam Al Kinda, Bashayer Al Hammadi, Fatima Ghazwan, and Samar Mohamed at Khalifa University for their assistance in selecting and supporting students from their respective institutions. Finally, the authors would like to acknowledge the many presenters: Gerry Schneider, Amy Hsiao, Adriana Ceric, Paul Heidebrecht, Scott Mathers, Andrea Atkins, Grant McSorley, Sarah Burch, Nasser Abukhdeir, Tom Lee, Jennie Dann, Harry Marshall, Vanessa Schweitzer, Mary Wells, Rodrigo Costa, Sagar Rajendran, and Linda Churchill.

This work was supported financially by the N.S. Robertson Foundation funding of the Sustainability Hub in the Engineering Ideas Clinic at the University of Waterloo.

References

[1] IEA, "Internatoonal Energy Agency," 2021. [Online]. Available: https://www.iea.org/reports/empowering-cities-for-a-net-zero-future.

[2] CMHC, "Estimating how much housing we'll need by 2030," 13 September 2023. [Online]. Available: https://www.cmhc-schl.gc.ca/blog/2023/estimating-how-much-housing-we-need-by-2030.

[3] P. Gwynne, "MIT creates an engine to accelerate startups," *Research-Technology Management, 60(3),* pp. 7-9, 2017.

[4] A. a. P. J. Bright, "The Harvey Mudd Engineering Clinic Past, Present, Future," .*Journal of Engineering Education, 88: https://doi.org/10.1002/j.2168-9830.1999.tb00434.x,* pp. 189-194., 1999.

[5] W. C. a. D. S. M. Oakes, "Community-Engaged First Year Learning Community Paper presented at 2022 First-Year Engineering Experience.," in *2022 First-Year Engineering Experience*, East Lansing, Michigan, 2022.

[6] K. Parker and R. Igielnik, "On the Cusp of Adulthood and Facing an Uncertain Future: What We Know About Gen Z So Far," 14 May 2020. [Online]. Available: https://www.pewresearch.org/social-trends/2020/05/14/on-the-cusp-of-adulthood-and-facing-an-uncertain-future-what-we-know-about-gen-z-so-far-2/. [Accessed 8 Feb 2024].

[7] C. McPhee, M. Bliemel and M. van der Bijl-Brouwer, "Editorial: Transdisciplinary Innovation," *Technology Innovation Management Review,* vol. 8, no. 8, pp. 3-6, 2018.

[8] N. Ibrahim, "Douglas Wright Engineer-in-Residence for 2024," 2024. [Online]. Available: https://uwaterloo.ca/urban-engineering-cities/douglas-wright-engineer-residence-2024. [Accessed 8 Feb 2024].

[9] Minister of Municipal Affairs and Housing, Province of Ontario, "Bill 23, More Homes Built Faster Act, 2022," 28 Nov 2022. [Online]. Available: https://www.ola.org/en/legislative-business/bills/parliament-43/session-1/bill-23. [Accessed 8 Feb 2024].

[10] Planning and Development Office, City of London, "More Homes," 31 October 2023. [Online]. Available: https://london.ca/business-development/more-homes. [Accessed 8 Feb 2024].

[11] Design Council, "Framework for Innovation," [Online]. Available: https://www.designcouncil.org.uk/our-resources/framework-for-innovation/. [Accessed 8 Feb 2024].

[12] Centre for Teaching Excellence, "Reflection Framework and Prompts," [Online]. Available: https://uwaterloo.ca/centre-for-teaching-excellence/resources/reflection-framework-and-prompts. [Accessed 8 Feb 2024].

[13] D. P. Crismond and R. S. Adams, "The Informed Design Teaching and Learning Matrix," *Journal of Engineering Education,* vol. 101, no. 4, pp. 738-797, 2012.