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Using a University Campus to Expand the Understanding of Design for Human and Non-Human Stakeholders in First-Year General Engineering Students

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1.1 Introduction and Background

This complete evidence-based practice paper describes and evaluates an assignment which uses human and non-human groups on campus to illustrate the concept of stakeholders in engineering design to first-year general engineering students. Understanding context is an essential element of design, and assessing stakeholder groups is an important part of this process. A large land-grant university campus is a built environment full of stakeholder groups, with many different designs to serve their various needs. Its accessibility to and relationship with students makes it a potentially useful tool to explore how designs and their users interact.

Design is a central element of engineering, and therefore a dominant theme in engineering education [1,2]. Understanding and engaging with stakeholders is an important part of this process [3]. For example, human-centered design is increasingly present in engineering education [4,5], and focuses on stakeholders and context to make designs more friendly to humanity [6]. While design and stakeholder interaction generally focuses on humans, there are examples of non-human participants in the design process, bringing particularly broad viewpoints [7]. Similarly, our program takes an approach to teaching engineering and design that is heavily focused on understanding and exploring context and stakeholders, as a means of developing engineers who understand that a successful design must work in the real world.

The first semester of the first-year general engineering program focuses on a project in which students learn to think about context. This is done by asking students to identify, explore, and structure complex problems affecting their lives on campus. In part of this project, students identify stakeholder groups and conflicts at the core of their problems of interest. The identification of stakeholder groups is something with which our first-year students sometimes struggle, focusing primarily on the obvious players: students, faculty, and staff. Similarly, their writing about ethics and environmental concerns can be simplistic if they are not actively challenged with these topics in class discussions.

While the terms “users” and “stakeholders” usually imply human or human-organized entities, there are many non-humans that inhabit or interact with a university campus. These non-humans can be just as important to consider in design. Landscaping choices can dictate the communities of plants and animals that make a space feel comfortable. Pest activity must also be managed or prevented. Other species that aren’t noticed or don’t interfere with campus life may also move in to take advantage of the opportunities available, using or modifying parts of the campus for their own purposes. The myriad interactions of living things with the campus, whether intended or

not, can provide examples of environmental impact and integration of design. More importantly for this course, they can also provide an opportunity to help students understand how to think about stakeholders during the design process.

To expand student thinking about design, environmental issues, and stakeholders, an assignment was developed and administered that asked students to identify and describe examples at the confluence of these ideas, leveraging the campus as a learning tool. This paper assesses the assignment, and reports the results of these student explorations.

Specifically, this paper addresses the research questions: 1) Can students identify stakeholder considerations in the design of elements of the campus built environment? 2) What design elements of the campus built environment are students most likely to notice and discuss? 3) What human and non-human stakeholder groups are students most likely to notice and discuss?

1.2 Course Context

This assignment was given as part of the two-semester first-year general engineering program at Virginia Tech, which all engineering students must complete before selecting a specific major. This program serves over 2000 students each year, and feeds into 14 discipline majors. In the first semester, students focus on strategies to understand engineering problems, including research on context, and problem definition. In the second semester, students focus on the design process. Throughout both semesters, students develop various technical, writing, and research skills. Much of this experience is structured around team project based learning.

1.3 Assignment

The assignment (Appendix A) was designed as a photo scavenger hunt, which students could do in person, or virtually as quarantine or location dictated. For the assignment, students were asked to find six examples of interactions between stakeholder groups and elements of buildings, the landscaping, or infrastructure of the campus. These were to include one each of designs supporting, thwarting, and appropriated by human stakeholder groups, and one each of the same for non-human stakeholder groups. For each of the six examples, students provided a photograph and a short written description identifying the stakeholder group, the design, and how and why that design related to those stakeholders. To assist in student comprehension of this idea, links to articles with examples were provided for each of the six categories. These examples were selected to share a range of scopes while avoiding things that would specifically be found on our campus.

The data used in this paper were all taken during the Fall 2020 semester, which due to COVID-19 was administered remotely. A secondary motivation for developing the assignment

was student reports of feeling disconnected from the university, and of being cooped up in their dorms for mostly remote classes. This assignment created a structured opportunity for those students who were not quarantining to engage with the campus as a whole in an individual way.

2. Methods

Student submissions were analyzed, identifying and coding the elements and stakeholders in each of the categories. When students supplied more than one example in a particular category, only the first example presented was included. Codes were applied according to the student's interpretation and presentation of the design or stakeholder group. For each example, the stakeholder group and relevant elements of the built environment were recorded, and categorized according to common selections (e.g. handicapped persons, elevators). Design elements were categorized by system (i.e. building structure, building services, landscape, specialty/amenity structure, and infrastructure). Human stakeholder groups identified were coded by proportion of users (all users, or a subset). Non-human stakeholder groups were also coded by proportion of users and groups (i.e. ecosystem, community, population (individual species), individuals), and by taxa (e.g. cockroach: animalia, arthropoda), but are presented using common names for higher level taxa. Additionally, for assessment purposes, coding included an assessment of whether the example was based on a significant misunderstanding, typically of the stakeholder or design. Frequencies of themes were tallied. Stakeholders and elements of the built environment representing >5% of submissions for a given category were reported.

Design element system codes were applied according to the focus of the student's description. In cases where students indicated more than one, each code was applied. Each code was defined as follows. Building (structural) design elements were those that centered on structural elements of buildings (e.g. an archway or ceiling corner), or entire buildings (e.g. a dorm). Building services were defined as non-structural elements of a building's environment, including utilities and services (e.g. water distribution pipes or sinks), or other managed elements of the building. For the purposes of this work, this also included indoor amenities and furniture supplied by the university, such as dorm-room bunks. Landscape was defined as designed outdoor elements, including planted and paved areas (e.g. gardens, paved walking paths), and outdoor furniture and user-support elements (e.g. park benches, trash cans). Specialty and amenity structures were those designed structures and spaces that stood apart from landscaping with particular purpose, but were not human-occupiable buildings (e.g. sport courts and fields, chicken coops, dumpsters). Infrastructure design elements were part of large-scale utility or transportation networks (e.g. roads, power lines, bus stops).

Coding of non-human stakeholder groups was applied according to student description. For the proportion of users and groups section, the largest group scope discussed was applied. In biological sciences, population means local members of a specific species, but was defined more

loosely in this analysis, as students did not actually identify scientific names of species. Instead, this code was applied when students mentioned only one common use name of a group for which there are only one or two species typically present on our campus (e.g. ducks, geese, squirrels), or it was clear the student was unaware of the differences (e.g. mosquitoes). Community was defined as two or more groups meeting the population definition used above (e.g. ducks and geese, squirrels and bunnies), or wording obviously including multiple types (e.g. bugs, insects). Ecosystem was selected when students used the word "ecosystem", or indicated the combination of biotic and abiotic components of the space.

Non-human stakeholder groups were also coded by the smallest clade presented by the student, and later combined in analysis into higher levels (e.g. all plants, all animals). Fish, a paraphyletic group, was also included, according to common usage. Likewise, viruses and bacteria were combined, as it was clear from the submissions that not all students understood the difference, or which category applies to COVID-19. Common names of taxa were used in presentation of the analysis, for the sake of clarity with an engineering audience, and to be consistent with the usage of the students.

3. Results and Discussion

This assignment was given to three sections of the first-semester general engineering course during the Fall 2020 semester. After student consent, institutional review board approval, and compliance procedures, a total of 158 submissions were available for analysis.

The scope of the designed systems of the built environment selected by students was relatively varied for most categories (Table 1), particularly for the human-related designs. Landscape elements were common in each design relationship, as they include many of the common specific designs (Table 2), including accessibility ramps, bike racks, fences, and trees. The most common element thwarting humans was card swipe door access, which is also evident in the building services scope being most represented.

The human examples leaned heavily towards student-related designs (Table 2). While the code was only applied to explicit mentions of students, it should be noted that most of the human-related designs had implicit indications that they were relevant to students. The other primary large classification of university users, faculty/staff, were barely mentioned, though again were implicit in some cases. This suggests that students mostly think about students when considering the design of the built environment on campus. The other general category was "sports-related", which similarly is mostly focused on students on campus. A particularly popular item for the thwarting and appropriated-by categories was a basketball court on campus, from which the hoops had been removed to prevent close quarters sport. Perhaps unsurprisingly, students instead began using this court for roller-hockey, soccer, and skateboarding.

Table 1: Scopes of designed systems represented among submissions (n = 158).

Scope of Designed System	Humans			Non-Humans		
	Supporting	Thwarting	Appropriated	Supporting	Thwarting	Appropriated
Infrastructure	9%	15%	6%	3%	4%	11%
Building structure	17%	9%	23%	8%	27%	21%
Building service	23%	40%	9%	1%	7%	11%
Specialty or Amenity Str.	12%	12%	25%	3%	4%	15%
Landscape	41%	28%	36%	83%	54%	46%

Table 2: Themes for human stakeholders (n = 158)

	Humans					
	Supporting		Thwarting		Appropriated By	
All users		46%		35%		14%
Subset		54%		65%		89%
Students		38%		18%		29%
Faculty/Staff		4%		1%		1%
Sports Related		18%		10%		32%
Common Specific Groups	Handicapped	22%	Unauthorized people	22%	Skateboarders	23%
	Bicyclists	14%	Basketball players	6%	Hammocks	5%
Common Specific Design Elements	Ramp	16%	Card swipe door locks	23%	Basketball court without net	18%
	Bike racks	9%	Fences	8%	Trees	11%
	Elevators	8%	Dismantled basketball hoop	6%	Buildings repurposed for COVID reasons	5%
	Campus quad	6%	-	-	-	-
	Walking paths	6%	-	-	-	-

Among non-human related designs, landscape dominated (Table 3). This is to be expected, as non-humans are generally meant to stay outside on a university campus. Higher counts of building structure elements were found in the “thwarting” and “appropriated by” categories, due to the focus on elements like window screens, and the tendency of non-humans to make use of sheltered areas on building exteriors.

Table 3: Themes for non-human stakeholders (n = 158)

	Non-Humans		
	Supporting	Thwarting	Appropriated By
Population	48%	25%	50%
Community	41%	73%	47%
Ecosystem	9%	1%	1%
Birds	53%	18%	23%
Mammals	31%	35%	27%
Insects	3%	15%	17%
Spiders	0%	0%	10%
Fish	11%	1%	2%
Plants	11%	4%	11%
Viruses/Bacteria	0%	6%	2%
Common Specific Groups	Ducks 29%	Squirrels 15%	Squirrels 21%
	Squirrels 22%	Raccoons 15%	"Wildlife" 5%
	"Wildlife" 20%	"Wildlife" 9%	- -
Common Specific Design Elements	Duck pond 34%	Trash receptacles 35%	Trees 9%
	Trees 16%	Locking trash bins 30%	Dumpsters 5%
	- -	Window screen 11%	- -
	- -	Fence 12%	- -
	- -	Bird spikes 8%	- -

In the supporting designs, almost a third of students specifically mentioned “ducks”, and a full third mentioned a duck pond on campus that was originally designed and installed to help manage stormwater. This is called “the duck pond”, with appropriate signage, and landscaping to turn it into a popular park. This was an obvious choice for an element supporting human

stakeholders. A smaller pond elsewhere on campus was occasionally also labeled as a “duck pond”.

Another popular non-human population was “squirrels”, commonly selected in all three design categories. In our campus with many trees, squirrels may be the most commonly encountered and observed non-human mammals. In both “supporting” and “appropriated” categories, students often discussed landscaping in general, and trees in particular, as the designed elements with which the squirrels interact. This raises the question of whether squirrels were intentionally considered as stakeholders in the designs, or are just a natural consequence of the landscape in this region. In coding, both interpretations were considered correct. Squirrels were also included in the “thwarting” category, most often in relation to trash receptacles, though seldom mentioned in this way without other mammals.

Students used the catch-all term “wildlife” in many cases in all three design categories. Sometimes this was the most specific group mentioned, and other times it was a way of indicating that the student was aware of other animals beyond their specific mentions. It is included here because the use of that specific word is a source of uncertainty in interpretation, as its definition may vary between “undomesticated animals” and “all undomesticated living things”, depending on who is writing.

Animals were much more frequently mentioned as stakeholders than plants, which were explicitly mentioned in 11% of the supporting and appropriated design examples, and 4% of the thwarting examples. Plants were more often treated as design elements than stakeholders. This may be a conceptual issue, as landscaping is mentioned in the assignment. It may be informative to add an example that is about a plant to one of the categories in a future iteration of the assignment.

Some, but not all, of the examples given in the assignment were strongly represented in student submissions. As noted above, the term “wildlife” was used, and was in the title of one example. Similarly, the bear-proof trash can example was applied to self-locking garbage cans on campus, which are inaccessible to most non-human animals. Skateboarders and bicyclists were also well represented as stakeholder groups, though the example designs were not present. In future versions of the assignment, it may be useful to select examples that are less relatable to campus, or to the region. It is possible, however, that some students will still apply them. The homeless example was reflected in several submissions about bus stop benches, despite not having a homeless population around town, and one student also mistakenly assumed *Legionella* would be present in their air conditioning window unit, which was not water-cooled.

Misunderstandings were identified in 54 examples, or less than 6% of all examples (Table). Misunderstandings were primarily in the thwarting non-humans category, which represented

39% of misunderstandings, or thwarting humans category, with 22% of misunderstandings. While the cause of misunderstanding was not captured in coding, researchers had the sense that these misunderstandings were often about whether the design was plausibly intended to support or thwart a stakeholder group. One example seen several times was roads thwarting animal movements, which is generally an unintended consequence of road design, and therefore not what was asked. It may be helpful in future iterations of this assignment to more clearly specify "intent" in the description, or to add a fourth category of unintentional thwarting.

One other notable type of misunderstanding was students identifying non-living stakeholders. Four students identified "water" or "rainwater" as a non-human stakeholder, either being supported or thwarted, by drainage systems. Another student identified "sunlight" as a non-human stakeholder being thwarted (by window blinds). As the goal of the assignment was to expand student thinking about stakeholders, this could be interpreted as a success, but the author considers this to be a step in the wrong direction. It should be noted that students considering an ecosystem to be a stakeholder include abiotic components by definition, but the focus is on the system and interactions, and the nature of the assignment did not permit an analysis of whether students mentioning ecosystems understood that definition. Likewise, there is still debate around whether viruses are alive, but that is different from things clearly established as non-living, like water or sunlight.

Given that only 6% of submissions contained significant misunderstandings, the author concludes that students completing this assignment were able to use the campus built environment to identify stakeholder considerations in design, and to think through design intent and stakeholder interactions. While many examples were obvious, the goal of the assignment was to familiarize students with the concept of stakeholders in the context of design, and the vast majority of students succeeded in finding examples of design supporting, thwarting, and appropriated by both human and non-human stakeholder groups. That the misconceptions were most often found in the "thwarting" categories is a minor concern, but that may be resolved by a clarification in the language indicating that intent in design is the focus, rather than unanticipated consequence. Evaluation of that change will be included in future work.

4. Conclusions

This work demonstrates an assignment that can be used to help students identify stakeholder considerations in the design of elements of the campus built environment, and to better understand the concept of stakeholders. It also indicates the kinds of campus design elements and stakeholder groups that students are likely to observe. Together, these results describe the variety and complexity of student observations of human and non-human stakeholders for this assignment. While every campus is different, and the region will dictate the non-human communities present on campus, the groups indicated in this paper can be used to think through

and anticipate what students may find on any other campus. The author found this assignment to be a useful exercise for students, and will continue to use it in first-year engineering courses where understanding the context of engineering problems and the consequences of solutions are learning objectives.

While student response to the assignment was outside of the scope of this analysis, the author noted multiple mentions of "stakeholders" and of this assignment in particular in end-of-semester reflections, conversations, and feedback. The author was left with the sense that the assignment was positively received and memorable. However, evaluation of student sentiment about this or similar assignments is left to future work.

These results will be of interest to educators who teach students about design and context, particularly those who would like to broaden their thinking about stakeholders, environmental issues, and the unanticipated consequences of design. Assignments such as this may also be useful in surveying or exploring the visibility of non-human inhabitants of the built environment, and the ways in which they interact.

5. References

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Appendix A: Assignment Text

Purpose:

Getting creative in thinking about stakeholders can help engineers to predict how the real world will interact with a design, and plan or adjust accordingly. After completing this assignment, you should be able to examine a design in use and identify some of the stakeholder groups the engineers anticipated, or and some they didn't. You should also be able to explain how these groups interact with the design.

Task:

Many engineering projects affect systems that matter to a wide variety of entities. Any entity interested in or impacted by a design is called a stakeholder. One way of evaluating a design and its impacts is to consider how it affects these stakeholders. To do this, we can organize them into stakeholder groups based on common interests. These groups can range from small and specific (the families that live in a small neighborhood), or large and varied (all of the life forms dependent upon the flow of the Colorado River).

A university campus is a designed and engineered space. Engineers contributed to almost every aspect of the buildings, landscape, and infrastructure around you. When designing the campus, they had to consider the needs and desires of many stakeholder groups. However, stakeholder groups can form or change over time, so no engineer can ever anticipate every need. For this activity, you are to take the role of an independent assessor, examining a space on campus to identify current stakeholder groups and elements of design that affect them.

1. Design Supporting Human Stakeholder Groups
   Example: Floating Bicycle Roundabout (Group: Bicycle commuters)
   - Identify an element of a building, the landscaping, or infrastructure of the campus that was successfully designed to accommodate a specific human stakeholder group. Take at least one photograph of the element, preferably in use. Write a few sentences explaining who the stakeholder group is, what the element is, how the element was designed for them, and why.
2. Design Thwarting Human Stakeholder Groups
   Example: Anti-Homeless Design (Group: Homeless people)
   - Identify an element of a building, the landscaping, or infrastructure of the campus that was successfully designed to interfere with or disrupt the behavior of a human stakeholder group. Take at least one photograph of the element. Write a few sentences explaining who the stakeholder group is, what the element is, how the element was designed against them, and why.
3. Design Appropriated by Human Stakeholder Groups
   Example: Skateboarding in Pools (Group: Skateboarders)

    - Identify an element of a building, the landscaping, or infrastructure of the campus that is being used by a specific human stakeholder group that was not intended by the designers. Take at least one photograph of the element, preferably in use. Write a few sentences explaining who the stakeholder group is, what the element is, how they are using it in ways that were not intended by the designers, and why.
4. Design Supporting Non-Human Stakeholders
   Example: Wildlife Bridges (Group: Animals that live around or migrate across a road)
    - Identify an element of a building, the landscaping, or infrastructure of the campus that was successfully designed to accommodate or support a non-human stakeholder group. Take at least one photograph of the element, preferably in use. Write a few sentences explaining who the stakeholder group is, what the element is, how the element was designed for them, and why. Briefly explain how this is relevant to humans.
5. Design Thwarting Non-Human Stakeholder Groups
   Example: Bear-Proofing Trash Receptacles (Group: Black bears and other trash eaters)
    - Identify an element of a building, the landscaping, or infrastructure of the campus that was successfully designed to interfere with or disrupt the behavior of a non-human stakeholder group. Take at least one photograph of the element. Write a few sentences explaining who the stakeholder group is, what the element is, how the element was designed against them, and why. Briefly explain how this is relevant to humans.
6. Design Appropriated by Non-Human Stakeholder Groups
   Example: Waugh Bridge Bat Colony (Group: Colony of Mexican free-tailed bats)
   Example: Legionella in Water Heaters (Group: Legionella bacteria)
    - Identify an element of a building, the landscaping, or infrastructure of the campus that is being used by a specific non-human stakeholder group that was not intended by the designers. Take at least one photograph of the element, preferably in use. Write a few sentences explaining who the stakeholder group is, what the element is, how they are using it in ways that were not intended by the designers, and why. Briefly explain how this is relevant to humans.

Place your answers in the provided template.

Deliverables:

- .pdf of the completed template

Hints and Resources:

- If you are off campus this week, you can use whatever building or neighborhood you're in instead.
- If you are quarantined and have to stay inside, take a look around. There may be examples in your room, or visible from the window. Google Street View may also be useful.
- This is designed to take no longer than the time you'd spend in the one class session it replaces.