Comparing Organizational Structures: Two Case Studies of Engineering Companies

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Introduction
“Design is what engineers do, and the intelligent and thoughtful decision of the engineering curriculum should be the community’s first allegiance [1].” Yet, we find that engineering design only underpins a small selection of undergraduate courses in a typical engineering curriculum; diminishing the importance of the activity in engineering education. Comparatively, design is a ubiquitous activity in engineering company settings—the foundational work driving much of the activity being conducted by professional engineers. We posit that understanding professional engineering design practices, will help us to inform how to frame our design courses within engineering education and better prepare our budding engineers to be effective practitioners.

In the field of engineering education, there is a lack of research on professional engineering work [2,3]. Engineering education is often organized against the backdrop of claims about what professional engineering work is like without fully understanding the “work” of professional engineers. This makes it nearly impossible for engineering educators to know whether or not engineering education is preparing engineering students adequately to enter the workforce upon graduation. Actual observations of professional engineering work are critical resources for rethinking engineering education and making college-wide decisions on curriculum.

Engineering design is a complex process that has been simplified to embrace a systematic loop, which can be easily taught to students and utilized by professionals. It is well recognized that simplified design loops do not represent all aspects of design, and research in engineering education has addressed complexities; even so, there remain aspects of the design process that need further research. In particular, understanding how engineering design is shaped by factors like institutional and organizational structure.

Our prior work has led us to believe that design aspects like space and time organize the entire design process and need to be consider when planning and executing project [4]. Furthermore, we have demonstrated that engineering design is a truly social process. This idea of design as a social process has been discussed prior, such in the work of Bucciarelli and Trevelyan [5,6]. Design work gets done though constant negotiations between people as well as the combined cognitive power of a team along with all of their resources [7].

Throughout a two-year ethnographic study of university and professional engineering design teams, we investigate how phenomena like space, technical coordination, relationships, and organizational structure play important roles in creating a design experience. This paper solely focuses on the professional engineering companies observed in the study, and offers suggestions on how these findings can translate into considerations for engineering education. Our intent is that this research add to the body of literature seeking to understand the complexities of engineering design and allows us to rethink how critical, yet subtle components are used to frame and scaffold the design process. It also identifies how differences in organizational structure can impact the approach to the design process as well as the design work setting. We challenge
engineering educators to determine what experience they want students to gain and then to implement necessary changes to create this type of design environment.

**Research Question**

All of this leads directly to the primary research question in this study: *what are the organizational structures of two different engineering companies and how does this impact their approach to design?* The answers from this question will better inform our understanding of professional practicing engineers and their approach to the design process, which will eventually lead to reforming undergraduate engineering design curriculum.

**Conceptual Frameworks**

This qualitative, ethnographic study uses a combination of three conceptual frameworks for examining practices of engineering design in companies. The three frameworks are Actor-Network Theory (ANT), Heterogeneous Engineering, and Situated Cognition, which will all be described more specifically in the following sub-sections. This combination of frameworks allows the research team to study engineering design in a novel way through placing importance on aspects like social interactions and the physical space where design work occurs. Only a qualitative study can truly get at these design subtleties, like relationships and interactions, and is the reason for approaching this research this way. As a qualitative study, we are able to combine the most important aspects of these three frameworks to guide our understanding of design: observing both human and non-human elements (from ANT), understanding the active stabilization of these elements which form networks (from heterogeneous engineering), and witnessing how situations are constructed through the interactions of multiple parts of the networks (from situated cognition). All of this together will allow us to look at how the organizational structure of a company can have implications on the design work done there.

**Actor-Network Theory (ANT)**

Engineering design is a complex process that has many human and non-human actors in it. It is logical then to use ANT, which has emerged from the field of Science and Technology Studies (STS), to map out all of these connections between the actors, as well as to provide a level of significance to each of these connections \[8\]. Actors, in this sense, can be human, such as engineers, project managers, suppliers, clients, and so forth. There are also non-human actors, which include things like design drawings, prototype models, CAD programs, the company-building layout, and the time allotted for tasks. ANT urges researchers to “follow the object” and “follow the actor” in order to see a complete picture of all the interactions with that object or actor \[9,10\].

It is essential to recognize the level of importance between these different actors, too. An example from observations is a mechanical engineer using a CAD program to design a prototype based off of the customer specifications. This engineer consults a colleague in the office next door about a certain CAD function to use while designing the prototype. There are multiple interactions occurring in this simple situation, such as between the engineer-CAD program, engineer-colleague, engineer-space (which allows quick access to the colleague thus also creating engineer-time), and even colleague-CAD program. This list of connections between actors could go on and be mapped for every type of interaction that occurs, both between humans and between humans and nonhumans.
These different interactions have a varying level of importance that can be assigned during analysis. The engineer-colleague interaction could be considered a “low-level” interaction, thus less important, if the engineer does not actually use the colleague’s feedback or rarely asks this person for advice over the course of the project. However, it could end up being a “high-level” connection if the colleague is providing extremely beneficial information in a timely manner to the engineer, who then uses that information to speed up his/her design work. Overall, ANT will allow us to start creating these networks that will then be further analyzed.

**Heterogeneous Engineering**

This ethnographic study was also approached within the conceptual framework of heterogeneous engineering. Heterogeneous engineering sees engineering in a new light, one that ignores the basis that engineers use technical knowledge just to create technical products\(^{[11]}\). Instead, this theoretical lens sees engineers as an active part in the whole process of designing, and views aspects like negotiations and interactions as equally as important as the technical aspects\(^{[12]}\). Additionally, the notion of heterogeneous engineering also sees human and non-human elements as important, and believes that they are all constantly trying to “stabilize the system” that they are within. In this research, the “system” is the design project or the design process and all of the human and non-human actors are working to constantly stabilize this system so that progress can be made (*i.e.* the design process can be followed and the project completed). This means that during observations, it is important to see all of these actors, but then also understand what importance they are in moving the design process either forward or backwards, thus “stabilizing” the overall system.

An example of heterogeneous engineering from our observations is when an engineering company holds a meeting with one of their current clients. This meeting, seen without the framework of heterogeneous engineering, observes a group of individuals sitting around a table discussing the progress on the project to date and the critical path moving forward. However, by taking a heterogeneous perspective of this situation, we see that each person brings a different background and perspective to the table. We see how negotiations are done, both verbally and nonverbally, and look at specific instances for why and how a decision was made. The relationships between people in the meeting play a part in these negotiations and also need to be weighed when considering how the “system” (the design project) is being stabilized. Also, it takes into account the time allotted for the meeting, the physical space of the room, and the technology or physical tools used during the meeting and conversations. There is more happening in that room than updating a client on the project’s progress. There is a constant back-and-forth between what the client hears, thinks, and says and what the design team interprets, understands, and does.

In this sense, what is being engineered is not just a technical object; rather, engineering does produce technical objects, but also persons, organizations, and everything that is part of the system that constitutes that technical object. The room of the meeting is being engineered and the relationships are being formed as well. All of these important parts of the design process are interrelated components used to support the design process, and are critical to the success of the project.
Situated Cognition
The last framework guiding our study of engineering design is that of Situated Cognition. This cognitive science-based approach has led to a reconceptualization of the relationship between cognition and action \[^{13}\]. Prior theories of cognition had separated cognition and action. This results in seeing cognition as a purely mental process, resulting in action as an output. In contrast, this relatively new framework of situated cognition places primary emphasis on contextualized action. Therefore, it is rejecting the notion that cognition can be considered as a separate function from and prior to action \[^{14}\]. Situations are not given, but are constructed by actors in the course of activity \[^{15}\]. These actors being both human and non-human as ANT showed us. Cognition is not purely mental, but is rather constructed in an environment, with physical tools and people. A group of people can share knowledge with one another and use tools to gain insight as well. This is described as having “distributed” knowledge across people in systems of activity \[^{16}\].

In this research, an example of applying this theory is by looking at how a decision is made between several engineers in the testing lab. Instead of taking the answer as “yes” or “no,” you instead consider the spacing of the room, the body language of the individuals, the spoken conversations, the backgrounds of the people, the tooling and testing equipment, and so forth. There is much more that occurs during decision-making than simply making a decision based on knowledge within one person’s mind. It is important to remember to consider all of these “other” aspects when observing design spaces and decision-making.

Overall, qualitative research relies on frameworks, like these, to guide researchers in their observations. Through the intersection of Actor-Network Theory, Heterogeneous Engineering, and Situated Cognition, we were able to observe a wider range of activities that are occurring during design work that would not be readily captured by quantitative methods.

Methods
This research is approached as a qualitative, ethnographic study drawing on techniques from the Social Sciences \[^{17,18}\]. A qualitative approach was used in order to understand aspects of design work, like technical coordination and relationships, which could not possibly be capture simply through a quantitative study. The research has two unique settings at two engineering companies in the same geographic region, but of different sizes and industries. These two companies will be described in detail in the Design Locations—Case Study section. This research is currently at month nine out of a fourteen month study. Multiple observational methods were used to capture all the elements of participants’ activities. The research team visits each company between one and three times a week for between three and eight hours a day. A summary of the ethnographic methods used for data collection along with the amount of qualitative data collected can be seen in Table 1 below. There is a varying number of observational hours between the two companies based on the amount of access given to the research team by the company as well as the amount of time the researcher could spend there.
Table 1. Qualitative Data Collected

<table>
<thead>
<tr>
<th>Types of Data</th>
<th>Medium Aerospace Company (MAC)</th>
<th>Large Medical Company (LMC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observational Hours</td>
<td>100 hours</td>
<td>400 hours</td>
</tr>
<tr>
<td>Observational Field Notes</td>
<td>20 field notes</td>
<td>50 field notes</td>
</tr>
<tr>
<td>Informal Interviews</td>
<td>4 people</td>
<td>10 people</td>
</tr>
<tr>
<td>Formal Interviews</td>
<td>2 people</td>
<td>2 people</td>
</tr>
<tr>
<td>Artifacts</td>
<td>50</td>
<td>100</td>
</tr>
</tbody>
</table>

This study is approached with techniques for doing fieldwork in modern societies, and draws heavily on utilizing the participant-observer role in observations as well as conducting short, informal interviews whenever possible [10]. The researcher would engage in a participant-observer role while at the companies, which entailed both engaging in conversation with the employees as well as being a quiet observer in the background [19]. The researcher would ask employees some follow-up questions when things were unclear or seemed important, usually during more seemingly unimportant times. As the observations during the day went on, the researcher would fall back into more of an observer role unless called upon specifically. They began to “disappear” into the room and just take notes on what was occurring around them.

Informal interviewing is a technique often used while during observations [17]. These informal interviews are brief question and answer conversations between the employee and the researcher, where specific questions are asked that are of interest to supporting claims and themes emerging from the data. An example to exemplify this is how during one observation the researcher noticed an engineer employee working on a new proposal for potential project. The researcher recorded the different ways they saw the engineer work during the proposal writing. However, the researcher could not necessary “see” everything that was occurring, especially since they were there once or twice a week. By asking the engineer about their methods for obtaining information and writing the proposal, the researcher was able to identify not-so-obvious tasks like emailing a specialist in the field and a phone call with a colleague at a different company that occurred the previous day. By using informal interviewing, the research team is able to continuously double-check what is being recorded as well as gather information that is not as readily available through observations.

Additionally, artifacts were collected at each of the company sites. Artifacts are physical and digital representations of work that are either used or created by members of the team during the design process. Examples of artifacts from this research are photographed images of whiteboards that were written on by employees, layouts of the company building, physical prototypes created, the Gantt chart or project schedule, and even the documentation of the project along the way.

From the observations and interviews, the research team collected an enormous amount of data, as seen in Table 1. Analysis is being done through analytic memos, descriptive representations, several staged coding, reconstructive analysis, and mapping of activities [20]. Analysis occurred concurrently with the observations and data collection in order to see emerging themes. It is from
our initial analysis that we were able to identify reoccurring themes in the data between the two different companies. The analysis portrayed in this paper includes the use of a comparative case study between the two places as a way to examine how different organizational structure impacts the design process [21].

Design Locations - Case Study
There have been two professional engineering companies observed during this research project. They are drastically different from one another and provide an excellent platform for a case study comparison of the organizational structure and design process approach. The first is a medium-sized company in the aerospace industry, which will be given the pseudonym Medium Aerospace Company (MAC). The second is large-sized company in the medical industry, which will be referred to as Large Medical Company (LMC). The following sections will discuss these two companies in further detail, summarize the overall findings and differences between them, and explain how we can use these findings to inform our decision making in undergraduate engineering education.

The research team’s view on design work can be heavily linked to the frameworks used in this study as well as several design articles. Heterogeneous engineering shows design work as a constant negotiation of people and tasks [22]. Situated cognition emphasizes that the knowledge to complete a design project is constantly developed on the whole team through interactions with people and tools [12]. Trevelyan has explained engineering design as the process of technical coordination [6]. “Technical coordination ensures that all parts of design come together, but also highlights that design work is a social process that needs relationships and interactions between people to succeed. Likewise, Bucciarelli explores design as a social process that is full of uncertainty and ambiguity [5]. Therefore, in both of the design locations in this study design work is considered as all of the activities that take place on a project. This includes everything from an engineer doing data analysis on their personal computer, to design review meetings, to even the conversations between employees in the hallways. We looked at design as a social process with many technical components, and thus evaluate design in the different contexts based on this philosophy.

Design Location 1: Medium Aerospace Company (MAC)
The Medium Aerospace Company was established in the 1980s and has three locations across the United States. It specializes in space mechanisms, and has completed over 300 projects for government, public, and private sectors. There are approximately 50 employees currently, with continual projected growth. The observations took place at only one of the three MAC locations. We are in month nine of the observations. There are more than 20 observations completed here.

MAC: Facilities/Company Overview
Since beginning observations, MAC has expanded their facility from 3,000 to 7,000 square feet. This expansion occurred due to the in-flux of projects in the last year, resulting in more space needed and more engineers hired. In the last year, there was the opportunity to expand the facilities within the current building because the neighbor company moved. The new MAC building includes eight private offices, four shared office spaces, two conference rooms, two testing labs, one electronics lab, one assembly room, and one clean room. A floor plan of MAC can be seen in Figure 1, which was created by the research team since there was no official
company floorplans available. The building is equipped for product design and testing. Much of the machining or manufacturing is outsourced and then the parts are brought back to be tested, inspected, validated, and verified. MAC has client’s come to their office on occasion, but they also rely on visiting clients’ facilities or using technology to communicate with them.

![Medium Aerospace Company (MAC) Layout](image)

**Figure 1.** Medium Aerospace Company (MAC) Layout

There are several organizational characteristics identified for MAC, which can be seen in Table 2. MAC is a true medium-size company that has company procedures and regulations that need to be followed at all three of the locations, as well as a designated organizational hierarchy “on paper.” However, it still has a relatively low number of employees and because of this is able to still be flexible in certain aspects, like not holding formal meetings or requiring employees to dress in business-casual attire. The low number of employees allows them to form close, personal relationships, which creates trust and respect amongst colleagues. Additionally, there are no listed titles or employee name plates outside of their offices. This helps to create more of an equality amongst the employees regardless of their status. There is a balance between still being a “small” company but also implementing “large” company protocols, thus making MAC a medium company that is in an upward growing phase. It is interesting to follow the growing of the company as they win more client contracts and bid proposals, hire more employees, and expand their facilities.

**MAC: Employee Overview**

At the MAC location observed, there are 15 employees. All of the employees are engineers with various specialties – mechanical, electrical, software, computer, and systems. There is one Project Manager (PM) at this location that oversees all of the projects. The PM transitioned from the company headquarters and has been with the company for 7 years. There is one Chief Engineer, who has been with the company for 5 years. The remaining employees have been hired on in the last 5 years or less, with a majority of them being hired in the last 2 years. The number of employees has slightly fluctuated since the beginning of the observations because the company is in the process of hiring more engineers as well as phasing out the interns and temporary workers.
Most engineers are hired with prior experience, but there are also several engineers hired right from their M.S. degree. Prior experience does not necessarily have to be in the aerospace industry, but needs to be pertinent to the specific role. An example of this is the newly hired Quality Engineer, whom has no formal engineering degree but has worked in aerospace quality assurance for the last 20 years. The employees are usually assigned to multiple projects, and the company usually has between three and six projects occurring at any given time.

### Table 2. Medium Aerospace Company Observed Organizational Characteristics

<table>
<thead>
<tr>
<th>MAC - Organizational Characteristics</th>
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</thead>
<tbody>
<tr>
<td>No listed employee titles</td>
</tr>
<tr>
<td>No scheduled daily/weekly project meetings</td>
</tr>
<tr>
<td>Casual dress code</td>
</tr>
<tr>
<td>Flexible, yet long hours</td>
</tr>
<tr>
<td>All engineering/technical background employees</td>
</tr>
<tr>
<td>Company-wide design process protocols</td>
</tr>
<tr>
<td>Close, personal relationships with co-workers</td>
</tr>
<tr>
<td>Industry regulations and protocols</td>
</tr>
<tr>
<td>Project deadlines lead project importance</td>
</tr>
</tbody>
</table>

**MAC: Typical Day in the Life of an Engineer**

A day in the life of an engineer at MAC gives a clearer picture of how the company is run and how engineers begin to approach the design process. An overview of the organizational characteristics can be seen in Table 2. This “typical day” comes from the observations in the company during a regular day there. Each morning the engineer comes to work around 9 AM wearing blue jeans and a thermal long-sleeve shirt. He pets the chief engineer’s dog who is lounging in the entrance way. He starts chatting with a co-worker in the hallway and discuss his weekend plans, but then also the most recent test results from the lifecycle test on the flight hardware for one of his projects. This co-worker would enlighten him on the data and also suggest a few new ideas about how to improve the design based on the initial findings. Soon, the engineer would find himself at his office able to check his email and look at his personal schedule for the day. There are no scheduled meetings except for a potential client meeting at the end of the week.

An hour later, the project manager (PM) comes by his office and lists off a half dozen new tasks that needs done. The PM then inquires about the newest test results data. The engineer prints out the results and then tells the PM he has a few questions regarding it. The PM takes this printed data and says he will go ask the chief engineer if he has any suggestions or recommendations for moving forward. As the PM leaves to find the chief engineer, the engineer is left with a new set of tasks for the week that he has to prioritize. He approaches these problems by consulting his co-workers in the office right near him, by emailing a few contacts in the field, and by tweaking an old data analysis code that a colleague sent him. He is able to get responses for half of the questions almost instantaneously through his contacts and co-workers. However, the other few problems are so new and complex that he needs to run his own calculations over the next few weeks to come up with solutions. In his mind, he sees this week as being a heavy work load and he will be spending close to 50 hours working on these new tasks with no solutions, yet. But he
knows that if everything goes well, that next week will allow more flexibility in his schedule and he can take off next Friday to head out of town for a long-weekend. Throughout the rest of the day today, the engineer has ten co-workers come by to ask questions about specific project-related tasks. The PM stops by about five more times to ask brief questions and then runs off again. This is a typical day for an engineer at MAC.

Each day for the engineer is different from the prior. There is extreme flexibility in the schedule based on the work-load at the moment. There are rarely any meetings or required events for the employees. Instead, the employees are all equals within the company and can go from office-to-office to ask questions freely. There are numerous resources, both people and tools, that can help guide the process forward and that the engineers at MAC can utilize.

**Design Location 2: Large Medical Company (LMC)**
The Large Medical Company is a global medical technology organization that specializes in the design and development of surgical and patient monitoring products and services. LMC has several thousand employees and 8 major locations in the US with more than 20 supporting offices world-wide. Observations began at LMC nine months ago and are on-going. These observations occurred at only one LMC location. There have been two major product design teams followed during the time there. The one project team was in the final stages of completion and the product launch occurred during the observations. The other project was in the initial phases and the research team was able to begin observations during the planning phase. This design project is scheduled to finish in one year after starting, and the research team plans to follow this team throughout its entirety.

**LMC: Facilities/Company Overview**
LMC is in a single building that contains numerous meeting rooms, cubicles, offices, manufacturing space, testing labs, and more all within a two-acre plot of land. The layout of the facility is in Figure 2, which was an obtained artifact from the company. LMC is a self-contained design and manufacturing firm, a workplace that is active for approximately twelve hours per day, and where employees have designated workspaces: cubicles, meeting rooms, testing labs, and the like. LMC is in the process of phasing out manufacturing at this location, and instead moving it to another country. This location will then solely be focused on the development of the product design.

LMC’s building concentrates virtually all of the activity of the company in a single, relatively small space, and serves as a common location for its employees’ day-to-day work. Employees have a designated cubicle that is surrounded by other members of the design team, and LMC management has spent a lot of time thinking about how to place people to achieve the greatest success. All of the marketing employees sit together in one corner of the building and all of the research and development engineers sit in another corner of the building. The building is constructed so that engineers can easily reach someone they need, from the project manager who identifies the most important tasks to meet the deadlines, to the quality assurance engineer who either passes or denies the product drawings. It is common for employees to run into someone on the team while walking down the hallway and ask a question.
There are regular scheduled “morning meetings” where the team gathers for fifteen minutes to discuss any challenges, as well as a one hour weekly group meeting where all the progress and hold-ups are addressed. Only the engineers attend the morning meeting, while the entire team (executives, finance, marketing, manufacturing, supply chain, etc) attends the weekly meetings. LMC approaches design in a “lean product development” way. They have implemented changes to their procedures to try to eliminate mistakes, shorten the time between when a problem occurs and when it is solved, and keep on schedule. One of these changes include using a new computer software for creating schedules, assigning tasks, and updating progress. LMC has also mandated these morning meetings as part of the design project, where every morning the whole team gathers between 8-9 AM for a segmented fifteen-minute slot and they discuss the progress from the previous day, the tasks slotted for today, and any challenges that have occurred. There are certain apparent organizational characteristics of LMC, which are summarized in Table 3.

Figure 2. Large Medical Company (LMC) Layout

**LMC: Employee Overview**

Engineers are dressed in business-casual attire daily and attend regular scheduled meetings for their projects and for the company. The engineers at LMC arrive for work in the early morning between 7-8 AM and leave in the evening between 4-6 PM. All of the engineers are secluded in the “engineering” section of the building and have small cubicles. Each employee has a name block and title attached to their cubicle. This allows everyone to know who the person is and how significant their role is in the company. Their time is spent with other engineers who are working on the same or similar projects. Engineers are usually assigned to one or two projects at a time, making them split their time amongst these different projects, which are all typically at different stages on the way to completion. These projects are dictated by the marketing team, who has surveyed the current devices on the market and then pushes LMC to design based on these customer and target needs. The most salient organizational segmentation of time at the company is a project, which often last for three or more years. There is a mix of employee backgrounds at LMC, and although the engineers usually work amongst one another they do interact with the business and manufacturing employees as well. Most of the engineers at LMC
have worked there for several years, with some having spent over thirty years at the company. There are not many entry-level engineers hired. Because of the length of time engineers are at LMC, there results in a great deal of continuity in knowledge from one project to another. Knowledge is made available to the rest of the company from these engineers and through all of the documentation kept during past projects. Industry and company protocols and procedures drive the projects at LMC, and are the reason there ample knowledge stored from prior project experiences.

Table 3. Large Medical Company Observed Organizational Characteristics

<table>
<thead>
<tr>
<th>LMC - Organizational Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Titles given to everyone and placed on desks</td>
</tr>
<tr>
<td>Scheduled daily and weekly project meetings</td>
</tr>
<tr>
<td>Business-casual dress code</td>
</tr>
<tr>
<td>Standard and long hours</td>
</tr>
<tr>
<td>Mix of engineering and business employees</td>
</tr>
<tr>
<td>Design process protocols</td>
</tr>
<tr>
<td>Business-relationships with colleagues</td>
</tr>
<tr>
<td>Industry regulations and protocols</td>
</tr>
<tr>
<td>Company priorities lead project importance</td>
</tr>
</tbody>
</table>

LMC: Typical Day in the Life of an Engineer

The “typical day” for an engineer at LMC was taken directly from observations that occurred at this site. An engineer’s work at LMC also varies day-by-day based on the project needs. However, there are certain aspects that stay constant throughout the time there. Every morning, there is a stand-up morning meeting where all members of the design team gather around and discuss problems and challenges. This is a time that is supposed to be used for connecting people to solve problems and making others aware of the current status of sub-sections. All of the daily and weekly scheduled project meetings are to keep the project on time. However, we have already seen one project delay their product launch for four months, even with having all of these lean product development protocols put in place. Also, the typical engineer is often split between two projects. One of these projects is on a “high priority” from the executive level, while the other project is considered a “low priority.” Engineers want to work on these high priority problems and this causes them to put more effort in on that project compared to the low priority other project. This categorizing of projects by a large corporation can cause focus to drift and levels of ambition and caring to vary in case-by-case situations.

On a typical day, the LMC building is relatively quiet. All the engineers are in their cubicles and working on their own tasks. They rush to finish tasks before the ritual morning meeting where they must report out to everyone. They head to the meeting one minute before it begins and are almost always late. Morning meeting lasts five minutes on average since it is not always used for its intended purposes. The person running the meeting rotates every day, and there are many engineers on the team that prefer not to fill this role. Therefore, they make the meeting as short as possible and do not push their co-workers to give more information. The day for an engineer after morning meeting is usually filled with more meetings – one with the marketing team, one whole company wide meeting, one with the electrical sub-group on a project, and one with the
whole project team. Each of these meetings last for about an hour and most employees in the meetings are on their computers. Their computers are used to pull up files for the meeting, but often also used for email or another task. There are approximately four hours of meetings each day. This leaves about another four for the engineer to work on their own tasks. An engineer will go seek advice from co-workers several times a day, but for the most part keeps to themselves in their cubicle. There is a tremendous amount of documentation that falls under the role of an engineer at LMC. Every time the project gets to a new step of the process, the engineers are required to fill out company mandated forms to track the progress of the project. This paperwork is seen as a tedious task, therefore it is placed at the bottom of most engineer’s to-do lists.

Work at LMC revolves on a pretty rigid schedule. Employees arrive at the same time each morning and leave at the same time each evening. There are several dozen hours of meetings each week for an engineer. There are substantial resources available at LMC, and engineers utilize these resources, but also spend a lot of their time working on problems themselves. There are also formal protocols that are followed and documentation that needs done.

Discussion
The initial findings suggest that organizational contexts constitute processes of design differently. Through this side-by-side comparison, we see how space, structure rigidness, relationships, and corporate standards can all impact the design experience. The organizational structure differs between the two companies observed based on their size. Both organizations are in highly-regulated industries, aerospace and healthcare, which does not seem to cause the variance between them. Instead, they differ in size, one medium and one large, which causes a different type of organizational structure to occur in the company.

MAC’s small space and low number of employees allows it to create a relaxed environment where everyone has both a personal and work relationship. The method for “getting things done” is by going and talking to an engineer in-person and getting feedback instantaneously. They do not use formal meetings to accomplish work and instead use their relationships and constant communication to naturally guide the design process. All members of the team are constantly “checking-in” with one another, which keeps employees on their toes and ready to tackle the next needed steps. There are formal documents that need to be completed, but this is never the focus of the work at MAC. Often, documentation is handled by the Project Manager, making this role fall less on the individual engineers.

Conversely, LMC is a highly regulated environment where there is a process or protocol to follow for everything that they do. The whole design process is formalized, which begins to take away from these relationships that form between the employees. Employees do get help from colleagues, but it is seen much less than at MAC. LMC’s approach for “getting stuff done” is by holding formal meetings. As one project was slipping behind schedule, the project manager would hold more and more sub-group meetings. However, in these meetings, the engineers would not be very prepared, or engaged, because they were too worried about the “actual work” that they needed to get done for the meeting itself. LMC also implemented a daily morning meeting that was aimed at getting a project on track and making sure that nothing critical would go wrong. These meetings seem valuable in describing them, but they are not utilized as
effectively as they could be. Instead, engineers start to de-value the daily meeting, thus having less engagement during them.

MAC and LMC are drastically different in their organizational structure. MAC has a flexible structure, while LMC has a more rigid structure. This variety in the structure causes a different culture in the company, thus resulting in a different approach to design. It is important to pay attention and understand the organizational structure of a company in order to begin to understand how that company “gets things done.” There are important tasks and steps that LMC has been able to formalize, thus making it easier on the life of the engineers as a whole. These protocols are needed in a large company. However, it is seen how engineers begin to de-value many of these steps, like writing up reports on each step of the work that is done or attending the morning meetings. From MAC, it is seen how having personal relationships and working in close proximity to all your co-workers leads to higher productivity and quicker turn-around times on tasks.

What Can Be Learned From These Cases
Overall, we can learn several valuable lessons from these professional engineering design cases that can then be applied to engineering education. Currently, design courses are structured down from ABET accreditation and what is needed to fulfill their requirements [23]. There have been movements to include more design education in the first year of engineers to encourage them to “stick with” engineering [24]. Some universities have a design-focused curriculum (e.g. Harvey Mudd, Stanford) where design is integrated throughout the curriculum [25]. In particular, size, space, organizational rigidness, and relationships are all important aspects to consider in design courses.

Lesson 1: Size
The size of a team or organization impacts the way the people interact with one another and the overall project/group [26]. There is some optimal (“small”) number of people on a team that allow for close relationships to form between team members or employees [27,28]. This could translate to engineering education by informing the way that large courses break down into smaller groups or sections. It could also help to identify methods for creating these close knit relationships, whether through cohorts or living and learning options amongst others [29]. In design education, it is important to consider the size of the teams and how that translates to the type of project and experience that students will have. Although important research has been done around team size, it is still an extremely important factor to consider when creating engineering design experiences for students.

Lesson 2: Space
Likewise, space is important [30]. Design teams need to be in close proximity with one another in order to reduce the time between having questions and finding answers. This allows the team to keep as close to schedule as possible, which is important in all design instances, but especially in the semester-bound academic time setting. These findings on space can be implemented into engineering education by re-evaluating the “space” used during design project courses. Teams could be allocated their own space in a building that they can use throughout the duration of the course and project [4]. This will allow the teams to have a place to meet and work together, thus allowing them to always be in the vicinity of one another. Also, design resources can be placed
within close proximity to these design spaces so that students can utilize all of the people and tools needed to help them in their overall project. These resources can include specialists in certain computer programs, machine shop, engineering subject-area experts, electronics lab, testing labs, computer stations, and the like. Space has a way of tying people to resources in the spaces, which adds to the experience that people have while designing. The space along with the proximity and allocation to resources (both people and material) need to be considered in engineering education.

**Lesson 3: Organization Rigidity**
The rigidness of a program also impacts the design process. Currently, universities structure design programs in similar ways\(^{[31]}\). Many university structures are rather rigid, like a large corporation, in that there are many protocols and procedures that need to be followed. Likewise, the university, or specifically the College of Engineering, is often considered a stakeholder or even a client in the senior design projects\(^{[23]}\). This structure in many universities causes senior design to be implemented like a large company. However, not all students will join large corporations upon graduating. There is a significant portion of students who join the workforce with medium, small, and startup companies. Therefore, it is equally as important to show students a variety of organizational structures.

Through our preliminary research, we have seen how these varying organizational structures approach the design process differently. We aim to help to start the conversation necessary to challenge the current organizational model seen in most universities. Overall, this research is highlighting the importance of recognizing organizational structures and how they impact designing and the entire design process experience. For engineering education, this requires us to look more closely at the entire university, college of engineering, departmental, and even course-level structure.

**Lesson 4: “Getting Work Done” – Relationships**
Through the study of professional engineers, we learn valuable lessons about how design work gets done. “Getting work done” occurs through social interactions, networking, and utilizing resources. These are some of the most important aspects to completing a design project. This social process of technical coordination is something that should not only be taught to engineering students, but also emphasized as critical components in the design process\(^{[6]}\). Engineers are often focused on the technical aspects of a design project and forget that design occurs through social interactions. This work can help continue the conversation about implementing more avenues for students to understand and recognize the importance of relationships, resources, and networking within engineering education\(^{[32]}\). It is important to include these aspects into the design courses. Currently, we have not seen a design course model where students’ grades are influenced by how well or not well they interact with others, from the departmental administrators, machinists, suppliers, to the financial coordinators. The way that these people are treated are equally as important lessons for the engineers to learn.

**Research Limitations**
However, this study has its limitations. The purpose of this research is to begin discussing how various groups approach the design process in different ways. These findings and implications are not generalizable, but rather important themes that emerged through the two case studies.
completed. We are aiming to start the conversation about how the approach to design differs based on the environment where it is conducted. Our work has shown through a small sample that varying organizational structures do change the way that design work is approached, which has allowed us to begin to discuss how we might reconsider the way we approach and teach design education in universities. But first, we need to determine what type of experience universities are trying to replicate – startup, small, medium, large, or all types.

Conclusions and Future Work
The findings from this research are significant because they have the ability to reframe the way we approach the design process. This could impact the way design is taught at universities and done at companies. By looking at companies that drastically differ from one another, this has allowed us to see that the organizational structure of a company lends itself to a different approach to the design process for a project. In particular, through comparing the Medium Aerospace Company to the Large Medical Company, we saw how different “spaces” frame the interactions between people, as well as how the rigidness of the organizational structure impacts the type of technical coordination.

The work during this project has shown that the organizational structure of a place directly affects the way the engineers approach the design project. It is important to consider this when starting or re-organizing a company. This also has implications in the university setting. The structure that surrounds and supports the design projects and the college of engineering all play a role in the design experience that the students receive.

More research needs to be done in order to better understand the organizational structures, underlying components, and intersecting networks that scaffold engineering design in companies and universities. Throughout this ethnographic study of professional engineering design teams in two companies, we investigated the complexities of engineering design by following teams throughout their projects. By looking at engineering design as the product of the organizational structure around it, insights were gained into what is happening during design and how design work actually gets done in companies.

In the future, we hope to observe more companies of varying size and industry, as to diversify the portfolio of design projects. Additionally, we aim to complete an in-depth analysis of the organizational structure and approach to design in the companies observed. The preliminary findings give us an insight into promising areas, like social interactions and formality of structures, that we can work towards understanding better. Ultimately, we want to create a model for understanding how companies approach design based on the size and industry of the company. This model would then be used to inform engineering education, so that students could be given the opportunity to approach design work in a multitude of ways as well as be informed about the different organizational structures that occur in the workplace so to prepare themselves for those varying situations upon graduating.

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References


