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DO VIRTUAL WORLDS AMPLIFY OR REDUCE COGNITIVE BIAS IN GROUP DECISION MAKING: AN INVESTIGATION DURING THE DESIGN OF A BIO-INSPIRED BUILDING

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ABSTRACT

Virtual design teams inherently bring new challenges to group decision making due to the technological barriers and lack of physical interaction. Therefore, the purpose of this research is to assess how spatially distributed engineering groups make complex decisions and whether a virtual work space amplifies or reduces barriers during the design of a complex system. The paper explores virtual design groups within a technological medium called the CyberGRID, which is a virtual collaboration and research environment. Students from four universities, spatially distributed across the world, were asked to collaborate and work together for one semester to design a bio-inspired building. Two of the four teams were required to meet in the CyberGRID while the other two were free to use whatever technology they wished. Research was conducted to examine two hypotheses. First, does the CyberGRID reduce or amply, a decision making bias, called the hidden profiles effect? Second, does the CyberGRID make group decision rules more pronounced? A hidden profile is the result of information not being distributed correctly amongst its group members. When used properly group decision making rules can help overcome cognitive biases like hidden profiles. For instances, delegation (one member makes the decision), plurality (each member has an equal vote), or unanimity (group must come to full consensus). A decade of behavioral science research suggests using a

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majority rule is best suited for a problem like designing a bio-inspired building because each group member holds unique information thus requires a collective pooling of information. After careful observations, interviews, and surveys the CyberGRID does reduce the hidden profiles effect, however it did not reduce the common knowledge effect (a subset of hidden profiles). The CyberGRID was also found to make group decision rules more pronounced and groups who used the CyberGRID ended up making decision that led to less conflict and more frequently employed majority rule approach.

KEYWORDS: Cognitive bias, virtual teams, group decision making, bio-inspiration

INTRODUCTION

Fifty years ago, being physically present on the jobsite was a necessity but today that is no longer the case. Recent advancements in technology have enabled globalization of the architectural, engineering, and construction (AEC) industry (Messner, 2008). Virtual jobsites mean owners are less spatially restricted to selecting architects and engineers. In addition, with rise in the cost of labor in many industrialized countries, companies frequently shift their services to countries with lower costs (Lewin et. al., 2005). Though, with changing technologies and shifting industry practices comes new challenges. These virtual design groups (also known as virtual teams) enabled by new technology are inherently more dispersed and complex than their in-person counterparts. Some of the challenges that accompany these virtual design groups include how to build trust, team cohesion, and team identity (Kirkman et al., 2002). Building trust is a challenge because of the lack of human connection in the virtual world. Trust is critical because it is an underlying construct to high performance.

As seen in Katzenbach and Smith’s book (1993), *The Wisdom of Teams*, teams go through four phases: norming, storming, reforming, and performing. In order to move from the storming phase (the least productive phase) into the reforming and performing phase (the most productive phase), teams must build trust, however virtual design groups inherently have a hard time with this step (Daim et al., 2012). If trust is not built, a team’s ability to transfer information amongst its members diminishes (Toma et al., 2009). This diminishing effect can result in a hidden profile. A hidden profile is the result of information not being distributed correctly amongst its group members. In a hidden profile, “information is distributed such that the sum total of information that the group collectively holds favors a superior alternative, but each individual member’s distribution of information favors another, inferior alternative. Each member alone cannot identify the superior alternative because they hold only a portion of the information that supports it” (Van Swol et al., 2003).

Therefore, the purpose of this research is to assess how engineering groups make complex decisions and whether a virtual world amplifies or reduces the hidden profile effect during the design of a complex system. More specifically, if effects of hidden profiles are more or less pronounced in groups that chose to use a virtual platform called the CyberGRID, a virtual world designed to facilitate construction group work. Four teams, composed of students from Virginia Tech, Georgia Tech, Washington State University, and Boğaziçi University, competed to design an energy efficient, low embodied energy, bio-inspired building. Each university had a specific role within the project such as life cycle assessment (Virginia Tech), project management (Georgia Tech), building information modeling (Washington State University), and energy modeling (Boğaziçi University). Two of the four teams were required to use the CyberGrid. In the form of avatars, CyberGRID users can explore and communicate with others in the computer-simulated environment. The purpose of CyberGRID is to provide user with the ability to visualize their designs in the virtual space, share documents, organize meetings, and hold real-time discussions.

This research is intended to provide insight on virtual design group decision making methods within the CyberGRID. In the next section, the hidden profile effect is explained from a behavioral science perspective, group decision making rules are discussed, and past research conducted in the CyberGRID is reviewed. Followed by the methods section, outlining the research setup and data collection process and analysis. Then results are presented that provide evidence of hidden profiles found among the engineering teams. The discussion and conclusion further rationalize these findings by comparing them to previous research and end with future opportunities to investigate cognitive bias in engineering group decision making.

THEORETICAL BACKGROUND & LITERATURE REVIEW

Behavioral decision science broadly deals with human action and often seeks to generalize about human behavior in society. The focus in this paper is more specific to behavioral decision sciences as it relates to group decision making. Group decision making at times can lead to amplifying cognitive biases (Sunstein et al., 2015) but done well can reduce individual bias leading to a better outcome. For example, groups are susceptible to effects that cause information to not be shared or shared inaccurately thus leading the group to make an inaccurate decision. Better understanding group decision making is especially critical in the AEC industry because decisions are rarely made individually.

Some of the more common effects described in the behavioral decision science literature that negatively impact group decision making are hidden profiles (Stasser & Stewart, 1992), common knowledge (Gigone et al., 1993), self-censorship (Hastie et al., 1983), over confidence (Heath et al., 1995), the popularity effect (Salganik et al., 2006), and cascades (Sunstein et al., 2015). The effect chosen to be examined in this research is the hidden profiles effect. This effect was chosen because virtual design groups are especially susceptible to this effect since trust is harder to build in virtual teams. Not trusting your team members can lead to information not being shared correctly, thus resulting in an ineffective decision, or in the case of this class an ineffective design.

Hidden profiles can drastically effect a groups decision, and make it so the group does not choose the best answer. With each individual member only containing a portion of the needed information, the discovery of the correct answer or choice is directly related to the group's ability to convey the information to the group. For example, in a research experiment when individuals were given 66% (or a majority) of the information for three political candidates (with one being the correct choice) the participants choose the correct candidate 66% of the time before discussion. After discussion, they were able to aggregate the information and pick the correct candidate 85% of the time, showing they could correctly share information. On the contrary, when individuals were given 33% (or less than half) of the information on the three candidates, the individuals only selected the correct choice 25% of the time before discussion. After discussion, surprisingly participants chose the correct answer even less showing they were not able to collectively share the information (Stasser et al., 1985).

Sadly, most groups do not convey the desired information, instead they convey the most commonly known information, thus hindering the group's ability to make the best choice possible. This sub-effect is entitled the common knowledge effect which is where the "influence of a particular item of information is directly and positively related to the number of group members who have knowledge of that item before the group discussion and judgment" (Gigone & Hastie, 1993). In other words, information is prioritized by the number of people who share the information, which is the exact opposite of what you would want when making a decision. In theory, to make an accurate decision, all information must be shared amongst the group members even if only one or two people share the information because that information could be essential to making the correct choice.

The common knowledge effect can have just as adverse of an effect as hidden profiles. In a research experiment where participants were asked to read descriptions about students and make individual and then group decisions on the student's grades, the researchers found that participants placed more emphasis on the information held by everyone than by information held by only one person (Gigone et al., 1993). Both of these effects, hidden profiles and common knowledge, can have negative impact on groups and our research is examining whether or not virtual environments make these effects more pronounced.

Group decision making rules are also essential to a groups effectiveness and when used properly these rules can help overcome cognitive bias like hidden profiles. Nine potential decision rules from behavioral science literature, as well as multiple combinations of these rules, may be used by virtual design groups. For instances, delegation (one member makes the decision for the whole group), plurality (each member has an equal weighted vote), or unanimity (group must come to full consensus). A decade of behavioral science research suggests using a majority or plurality decision rule, is best suited for the group to solve a problem in which no member could solve individually. Accordingly, majority rule is the most appropriate for a scenario like designing an energy efficient, bio-inspired building because each group member holds unique information thus requires a collective pooling of information.

Face to face group decision making has been well studied and documented. With the advent of new technology, virtual design groups are now becoming just as common as face to face teams however these virtual teams have not been studied nearly as much as face to face teams. Virtual teams inherently bring their own set of pros and cons. With the globalization of many industries, researchers are now becoming more and more interested in these virtual design groups and how to maximize their effectiveness. The CyberGRID is one attempt at researchers trying to maximize virtual design groups effectiveness using a construction industry approach.

BACKGROUND ON THE CYBERGRID

The CyberGRID, or "(Cyber-enabled Global Research Infrastructure for Design), is a virtual collaboration and research environment. The CyberGRID was designed to support collaboration across globally distributed design groups that engage in iterative design processes. The CyberGRID acts as a collaborative tool for team members to share points of reference in space (Iorio et al., 2011). Users interact in the CyberGRID like a videogame, allowing users to control an avatar and move around in a virtual environment. Some of the biggest advantages to using the CyberGRID over other virtual meeting platforms such as Skype or Google Hangouts is that the CyberGRID allows for "hand" motions, integrations of scaled Building Information Modeling (BIM), and the use of "team boards" (Iorio et al., 2011). The CyberGRID allows the use of "hand" motions through buttons located at the top of the screen. These buttons allow users to vote yes or no, "raise their hand" to indicate they have a question (a "?" appears over their head), as well as indicate to other members they have a comment to make. These buttons allow for groups to interact more as if they are meeting in person and less like they are meeting in a virtual environment. Another unique feature to the CyberGRID is the integration of BIM into the CyberGRID software. This allows teams to download their BIM models directly into the virtual world and then scale it down to the size of their avatar so they can "walk" around the building. This feature is useful for teams when group members are not familiar with BIM because it takes away that prerequisite BIM skills need to walk through the building and allows all members to contribute ideas to the model. It also allows for quick identification of mistakes, such as not placing a door in the right space. A chat feature is also incorporated into the CyberGRID. This allows for teams to not only communicate though verbal communication and the hand signs but also through written text as well. Sadly, most teams only use this feature to solve technical problems such as "Can you hear me?".

One of the last main features of the CyberGRID that differentiates itself from other virtual meeting platforms is the use of team boards. These team boards act like virtual white boards, where teams can share their computer screens for all members to view as well as allow other team members to mark up (through virtual markers). This feature is helpful when viewing construction drawings because instead of trying to talk your way through a design you can project your thoughts on the team board and have others provide comments with the virtual markers. Again, this feature makes the CyberGRID act more face to face meetings and less like a virtual world. These features are illustrated in Figures 1 and 2.

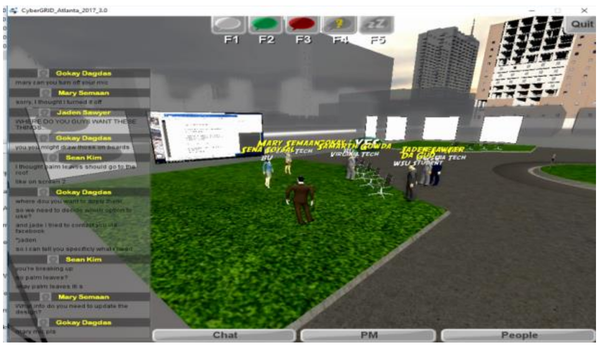

Figure 1: Team meetings within the CyberGRID

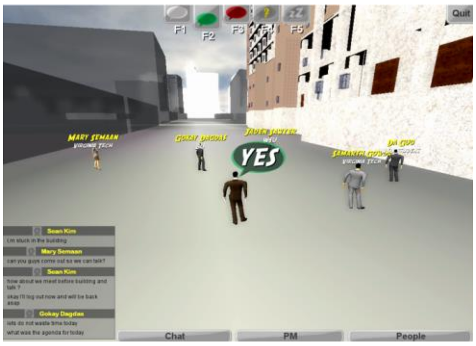

Figure 2: Team members voting in the CyberGRID

Similar to how group decision making can amplify cognitive bias, virtual teams appear to amplify power structures among groups. In teams of American, Dutch and Indian students, Indian students were frequently left out of the decision process because the American and Dutch students perceived them as less comprehensible (Iorio et al., 2014). The Indian students' short hand was a non-formal writing style compared to the Americans and Dutch. If the teams had been able to meet face to face, relying less on written communication, the Americans and Dutch participants may have formed a different opinion about their Indian team members. However, these barriers, once known, can be overcome through training. For example, prior leadership experience (as little as three months) can drastically play a role in the leader's level of engagement in transformational, transactional and technological leadership interactions in virtual project teams (Iorio et al., 2015). While prior CyberGRID research includes demonstrating how the power structure of teams influences communication strategies (Iorio et al., 2014), defining "messy talk" (Dossick et al., 2012), and the use of facilitators to transfer information among group members (Iorio et al., 2012). The purpose here is to uncover how the CyberGRID either enables or prevents better group decision making practices.

RESEARCH OBJECTIVES

The research objective is to better understand virtual design groups. To meet this research objective our research questions are:

1. How does the CyberGRID amplify or reduce hidden profiles?
2. Do group decision rules (e.g. delegation, unanimity) become more pronounced in the virtual world and which ones?

We expect to find that the CyberGRID assists the virtual design groups share information and make better decisions. More specifically, our hypotheses are:

1. Information not incorporated into CyberGRID but critical to informed decision making will result in less than optimal choices related to energy efficiency and net embodied energy included in the building because life cycle assessment of materials and energy efficiency calculations are not required to be incorporated into the virtual world.
2. Group decision rules will become more pronounced in the groups required to use the CyberGRID compared to the groups not required. The teams that follow a majority or plurality rule create better building designs, defined as more energy efficient, lower embodied energy, and more representation of bio-inspirational attributes in their building. Teams not required to work in the virtual world, we expect will use less pronounced decision rules. Decision rules followed are expected to be delegation rather than majority because delegation requires less frequent communication.

METHODS

Within this section, the class structure as well as the methods for data collection are explored in detail. The section begins with the class structure followed by data collection process.

CLASS STRUCTURE

Students from Virginia Tech, Georgia Tech, Washington State University and Boğaziçi University were randomly grouped together to form 4 teams. To better understand if and how the virtual world influences information sharing among group members and whether the virtual world effects group decision making rules among engineers, two of the four student engineering design groups were randomly chosen to use other forms of communication and two teams were required to use the CyberGRID each week. Over a three-month period, the teams completed their design for an energy efficient, low net embodied energy bio-inspired building. Below, in Table 1, are the universities, number of students and their responsibilities.

Table 1: University participants and their roles

University (Country)	No. of Students per team	Role
Georgia Tech University (USA)	1	Project Managers
Virginia Tech University (USA)	3-4	Life Cycle Analysis
Washington State University (USA)	4	Building Information Modelers
Boğazici University (Turkey)	2-3	Energy Analysis & Estimators

Students from Georgia Tech led the design as project managers and acted as site and content experts. Although the design was virtual, the site conditions were real. The site was located in downtown Atlanta, GA and required periodic site visits from each project manager. Virginia Tech students were responsible for calculating net embodied energy of the building using a life cycle assessment (LCA) approach. Virginia Tech students used Athena Software to complete their LCAs. Washington State University students were responsible for the building information modeling aspect and chose to use Autodesk's Revit software. Students from Boğaziçi University were responsible for energy calculations and payback periods for energy upgrades to the building.

The course was divided into three phases, Introduction, Design Build, and Finalization. The Table 2 summarizes each phase along with the expected deliverables from the students as well as when data was collected, and what type of data.

Table 2: Class Phases and Deliverables

Phase	Weekly Topic	Student Deliverable
Introduction	Week 3 – Introduction to urban Project Site, The Biltmore	Energy Retrofit Ideas Paper
	Week 4 – Leadership preparation	
	Week 5 – Team Familiarization & Team-building	
	Week 6 – General overview of Bio-Inspired Buildings	further
	Week 7 – Detailed Bio-Inspired Case Study Investigation	PowerPoint of the selected Bio-inspired building
Design Build **Observations will take place during each team meeting. Interviews took place directly after each team meeting. Surveys are distributed at the end of each week.	Week 8 & 9 – Familiarization with 3D Model and Actual Project Site, Bio-Inspiration and 3D Model Retrofit Planning	Preliminary Design Concept & Efficiency Goals along with a Team process Plan
	Week 10 – Finalized Retrofitted Model & Baselines	Submit finalized retrofitted 3D model
	Week 11 – Retrofitted Model & updated building specs	Submit finalized energy analysis, LCA, and cost estimate
	Week 12 – Iteration	
Finalization	Week 13 & 14 – Final Report	Submit written Final Report
	Week 15 – Prepare Final Presentation	
	Week 16 –Final Presentations	Present Final Report

The end goal for this class was to design a Bio-Inspired building that increased energy efficiently, increased the building's sustainability, and reduced operating cost from the base model. The teams had to work together in order to complete this task. Overall the teams had five weeks to finish the project and four weeks to prepare the final report. It is worth noting that each university's spring break fell on a different week and all of these weeks were subsequent (weeks 10-12). The final projects were evaluated based on the integration of bio-inspiration, energy efficiency model, and embodied energy of their retrofit. As mentioned before, two of th teams were required to meet each week in the CyberGRID while the other two teams were not required. Figure 3 illustrates a student meeting in the CyberGRID.

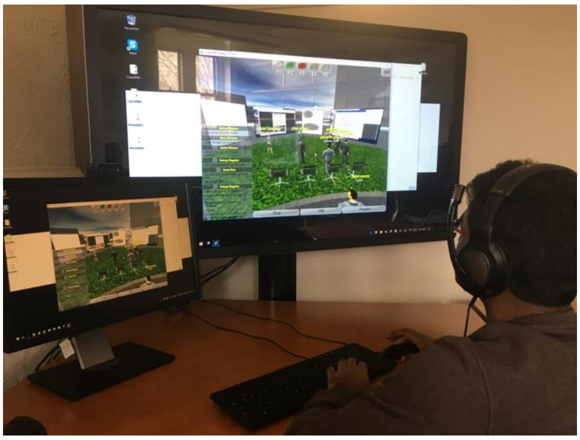

Figure 3: Student meeting in the CyberGRID

METHODS FOR DATA COLLECTION

We used a mixed-method approach to collect data, including: surveys, observation, semi-structured interviews, and document analysis of the final projects. To appropriately mix our data collection protocols were guided by Creswell (2013). Strategically, a diverse and collaborative research team was assembled to conduct this longitudinal study increasing the reliability and validity of our results. To ward off the Hawthorn effect, data collection points were stacked throughout the study and students were exposed to researchers frequently. The survey was sent to each student each week in a consistent and habit forming manner. The survey's main purpose was to collect how each group communicated, how often they communicated, what technologies they used, and the student's perception of the effectiveness of the communication. Observations were also conducted during each individual group session. Researchers were present in the lab throughout the class period and discretely collected field notes while teams conducted their weekly meetings. Only two of the four groups were required to use the CyberGRID. The groups who chose not to use the CyberGRID were interviewed instead. The researchers were physically in the room with the Virginia Tech students to take notes about the student's interactions both inside and outside of the CyberGRID. The form used to take notes during observation is in the appendix.

In particular, the researchers were looking for identifying factors that would indicate hidden profiles. Questions such as, did the students receive and stick to an agenda? Was the agenda structured? Prior research suggests that when teams receive a structured agenda and stick to it, hidden profiles are less likely to become apparent because the information necessary to share is being shared (Mennecke, 1997). How many times did the group discuss information that everyone already knew and/or had already been discussed? Information that is repeated and owned by others is viewed at a higher importance. Discussion of common knowledge can place a higher importance on this information and less importance on unique information needed to make an effective decision (known as the common knowledge effect, a sub effect of the hidden profiles effect) (Van Swol et al., 2003). Did the Virginia Tech students always voice their opinions through the CyberGRID or did they mute themselves and discuss information amongst themselves? These are just some of the questions and group practices the researchers were recording during the observations. A full list is provided in the appendix.

After the teams conclude their weekly meetings in the CyberGRID the researchers interviewed the student teams. Semi-structured interviews were used to support the surveys and observations and to record the students' perspective about how the meetings were conducted. During the interviews, the researchers asked questions that overlapped with the observation. For example, in the interview, the researcher would ask "How often did your team discuss information everyone already knew?" In effort to more deeply sense of how often the common knowledge effect occurred, in addition to confirming their observations, researchers asked the students how decisions were made both within the meeting and if any were made outside the meeting (such as over email or instant messaging). The purpose of probing about decision making was to gain a better understanding about how group decision making rules were structured within the virtual design groups. By using these three methods in concert, the researchers were able to identify and make comparisons whether or not virtual design groups actually amplify or reduece the hidden profiles effect and if group decision making rules become more pronounced in the virtual world.

RESULTS & DISCUSSION

The results in this section are broken into two sections, the first relates to whether or not the CyberGRID amplifies or reduces the hidden profiles effect and the second to group decision making rules. Two of the four student groups were forced to meet in the CyberGRID (for the purposes of this paper these teams are referred to as CyberGRID 1 (CG_1) and 2 (CG_2); the other two had the option to use the CyberGRID and are referred to as Non-CyberGRID 1 (NCG_1) and Non-CyberGRID 2 (NGC_2). The teams required to meet in the CyberGRID were chosen randomly. In addition, students were randomly assigned to teams. Below in Table 3, the teams are listed along with descriptive results about how each team engaged with the CyberGRID, as well as additional technology the teams decided to use.

Table 3: CyberGRID and Non-CyberGRID Team Breakdown

TEAM	MEETING DAY	CYBERGRID FUNCTION	OTHER TECHNOLOGY USED
CG_1	Tuesday	Utilized almost all of the features of the CyberGRID except for walking around their model.	Facebook (both Group and Messenger), Google Drive, Email, and Dropbox
NCG_1	Wednesday	Utilized the CyberGRID at its most basic form, as a virtual chat environment. Used no features such as team walls or voting bubbles.	Skype (for members who was not able to be in the CyberGRID), Google Drive, Email, and Facebook (messenger)
CG_2	Thursday	Utilized all features of the CyberGRID.	Google Drive, Dropbox, and Email
NCG_2	Friday	Did not meet in the CyberGRID	WhatsApp, Skype, Email, Google Drive

CG_1 and CG_2 were forced to meet in the CyberGRID during their assigned days (Tuesday and Thursday). During these days, observations and interviews also took place. CG_1 utilized almost all of the features of the CyberGRID such as the yes/no bubbles for voting, the chat feature (not just to fix microphone issues but to subsidized spoken work), the team boards as well as the marker/drawing feature within the team boards. CG_1 did not however use the CyberGRID to walk around their building to identify design errors. Whereas, CG_2 utilized all of the features of the CyberGRID including the ability to walk around their model. As a team, CG_2 would walk around the model and identify design errors as a group as well as potential areas for improvement. During the virtual walk-thru group members would ask questions to others in the group and make notes about how to improve design features for the following week.

NCG_1 and NCG_2 were not forced to meet in the CyberGRID, however NCG_1 decided as a team that they would try to meet in the CyberGRID at least once a week. NCG_1 did not utilize any of the features of the CyberGRID that made it advantageous to other virtual communication technologies. NCG_1 simply used the CyberGRID to talk with group members about the project and assign responsibilities. In essence, a platform for verbal communication not much different than a phone conversation. NCG_2 did not meet in the CyberGRID during the entire design project. Instead NCG_2 utilized a text based app called WhatsApp to message each team member. NCG_2 also used Skype to talk about project tasks and deliverables, however only the microphones were used in these meetings, none of the meetings included face to face virtual meetings using the camera option.

Every team utilized some sort of cloud based document manger, such as dropbox and google drive. Two teams, CG_1 and NCG_1, utilized Facebook groups to facilitate information transfer. All teams utilized emails to distribute information and assign tasks.

HIDDEN PROFILES RESULTS

Information was conveyed very differently for each team. CG_1, CG_2, and NCG_1 all shared information through meeting and communicated in the CyberGRID. The teams shared information by talking via the microphones and CG_1 and CG_2 also displayed information on the team boards. CG_2 even utilized the marker feature to illustrate their ideas. For example, students drew a chimney stack on the team boards to show how it could be used to ventilate the building. NCG_2 team did not meet in the CyberGRID. In addition to the observations and interviews, surveys were distributed and collected after each week. These surveys aimed to identify how information was shared and if information sharing was consistent. Over the course of the project, students from the NCG_2 team agreed they frequently made decisions without fully considering all options as well as they usually chose the easiest solution with minimal effort. Other teams sometimes selected that they agreed with the two statements (not considering all options and picking the easiest solution) however this was minimal compared to the students of NCG_2 who indicated they frequently did not consider all options and instead frequently chose the easiest solution more than 50 percent of the time.

A hidden profile is created when information is not shared correctly or when information is withheld for some reason. Information sharing in this research was seen most effectively distributed between teams CG_1 and CG_2 who were the teams that utilized the CyberGRID. CG_1 and CG_2 shared information in the same general format, through a conversation in the CyberGRID, however each team did have some unique ways in which critical information was shared. In some of the preliminary design meetings, the Virginia Tech students distributed research papers to each team member (through google drive) and then design features that could be adapted into their building from the research papers discussed.

Across the four teams, the Virginia Tech students' shared the mindset that *"It was everyone's responsibility to ensure they read the paper and understood the information."* While this approach seems pragmatic, it could lead to a hidden profile if team members were not prepared. Based on the interviews and observations, those unprepared for the meetings were more easily identified by their group during the virtual meetings in the CyberGRID than through text platforms like Whatsapp. A reflection from a Virginia Tech student, a member of NCG_2 team, made very clear that their team struggled to collaborate during meetings, stating *"students from University Bogazici and Georgia Tech rarely show up. Students from University Washington State University worked extremely slow and declined most of our suggestions for bio-inspired retrofitting."* On the other hand, CG_1 utilized the team boards to share information so that everyone understood the design both from the papers initially and the teams design through out the semester. CG_2 went a step further by sharing information utilizing the native features of the CyberGRID. CG_2 walked around the virtual environment in the CyberGRID in almost every meeting to identify design errors. While only a few design errors were found during this time, it allowed the team to become familiar with the actual 3D representation of the building rather than the 2D set of drawings. Seemingly due to interactive collaboration, CG_2 was observed to have few conflicts in negotiating design features.

NCG_1 did utilize the CyberGRID but mainly for its chat feature. Whenever group documents, pictures, or information were shared the group utilized google documents and or electronic sheets to convey the information, not the team boards within the CyberGRID. While this is not necessarily seen as a drawback, students on NCG_1 were unable to then utilize the marker feature to make edits, like CG_1 and CG_2. NCG_1 was also observed frequently repeating information due to the lack of consistent methods to share information and make real time changes. Out of the three groups observed each week (NCG_2 was not observed because they did not meet in the CyberGRID rather interviews were the main source of data supplemented with the weekly survey responses), NCG_1 most frequently repeated design information about their building. NCG_2, the team who never met in the CyberGRID reported in the interviews and surveys early in the design process to not be repeating information and viewed their group as both sharing and processes in place helpful in project performance. Come to learn, by the end of the design process, the group had not been communicating much at all. Rather, distributing tasks with little interaction between group members. Table 4 synthesizes the teams' use of the CyberGRID and how this relates to potential hidden profiles.

Table 4: Summary of observed hidden profile among teams

TEAM	CYBERGRID FUNCTION	HIDDEN PROFILE
CG_1	Utilized almost all of the features of the CyberGRID except for walking around their model.	Hidden profiles were minimized because of the extensive use of the CyberGRID. A hidden prolife could have existed when the VT students distributed content (e.g. research papers, agendas, briefs, etc.) without follow through from the team to prepare for the meetings.

NCG_1	Utilized the CyberGRID at its most basic form, as a virtual chat environment. Used no features such as team walls or voting bubbles.	Hidden profiles appeared sporadically throughout the design process because of the limited use of the CyberGRID. Information was shared but only through verbal communication. Often observer, information was "lost in translation" due to the cultural and language barriers of the team. In addition, assumptions were frequently made that the entire team had read all of the documents and reviewed all drawings prior to each meeting
CG_2	Utilized all features of the CyberGRID.	Hidden profiles were observed the least in this group. All features of the CyberGRID were used to share and communicate information. Much of the information was new (e.g. each week's Revit model was updated by students at WSU and shared via the CyberGRID through a walk through).
NCG_2	Did not meet in the CyberGRID	Hidden profiles were the most prevalent in this group even though the group failed to recognize the barrier. The use of text based messaging software limited the communication. It also reduced how much and how frequently information was shared. The technology allowed for document sharing but far less information was reported shared compared to the other groups.

Going back to the ideas found in Katzenbach and Smith's book (1993), *The Wisdom of Teams*. Teams go through four phases: norming, storming, reforming, and performing. In order to move from the storming phase (the least productive phase) into the reforming and performing phase, teams must build trust, however virtual design groups inherently have a hard time with this step (Daim et al., 2012). If trust is not built, a team's ability to transfer information amongst its members diminishes (Toma et al., 2009). All of the teams that met in the CyberGRID seemed to share information and communicate more effective than the group who never met in the CyberGIRD. Interviews with the teams that interacted in the CyberGRID were able to describe what their other team members duties and tasks were each week. And in the surveys, those who met in the CyberGRID believed their team members provided meaningful contribution to the project each week.

Via observation, it was found that the individual team members in CG_1 and CG_2 would often mimic face to face meetings through their avatars. For instance, avatars would stand around in a circle or sit in chairs around the whiteboard (exemplified in Figure 1 and 2 in the background section). Team members not sitting or walking around were often not part of the discussion. The teams who reported in the surveys their team members were all contributing, more likely were to select their team had made progress each week, and were less likely to describe barriers to making progress in the weekly interviews. In addition, it was apparent that NCG_2 team experienced more problems with their project (indicated on the surveys) along with more arguments than the other teams (identified through interviews). For example, in an interview with one of the Friday group members the student said, "*There are always problems communicating the design across the global team even though we are using a variety of communication platforms"*. Another student from NCG_2 said, "*I have no idea what the other universities are doing. They don't seem to be helping at all.*" In fact, all teams were required to make some progress for their individual class. Though, the work being done was not well communicated among the group not required to meet virtually through the CyberGRID. Frequently, students from Virginia Tech and Georgia Tech (team members not responsible for Revit drawings and energy models) would say in interviews that they do not have access to Building Information Modeling (BIM) files or they have not been given information about the building. Students at Washington State University were responsible for the modifications to the building using Autodesk Revit. Students at Virginia Tech from NCG_2 commented after 4 out of the 6 weekly interview sessions they felt powerless in progressing the project along because they were not able to see the building. Noted during the observations, the lack of ability to share information led to lack of direction during the meetings. While this alone is not indicative of a hidden profile existing, it appears that NCG_2's team had less trust among team members thus lead to less critical information being shared as well as the information not being shared properly due to the team's medium for meeting. Based on the observations and interviews, the NCG_2 team appears to never have made it out of the storming phase. The CyberGRID seemed to reduce the hidden profiles effect to some degree which allowed CG_1, CG_2, and NCG_1 to perform with less arguments and indicated both through the survey and they were aware and could describe their team members' tasks for the week.

The common knowledge effect, a subset of hidden profiles, is when "influence of a particular item of information is directly and positively related to the number of group members who have knowledge of that item before the group discussion and judgment" (Gigone & Hastie, 1993). After reviewing the observation notes and interviews transcripts, the common knowledge effect seemed prevalent in both the CG teams as well as the NCG teams. The virtual design groups all discussed information everyone already knew and or repeated information frequently. While the observers noticed students talked about the same information over and over again, interviews revealed that group members were not always aware of this repetition. CG_2 stated infrequent repetition during interviews, but observations and final reflection responses revealed otherwise. A CG_2 student from Virginia Tech stated, in their final reflection, "*I would advise future design teams to make a schedule and stick with it. We spent a lot of time discussing the same information from week to week without making much progress towards the end of the semester."* During observations, there were multiple weeks were technical information and objectives were repeated due to missed deadlines. Across the teams, students appeared not entirely aware of what information had or had not been discussed. This could be the result of the lack of using an agenda from all the teams. CG_1, CG_2, and NCG_1 never used an agenda and NCG_2 distributed an agenda for everyone to look at but did not follow it during their meetings. Studies have shown that the use of agendas greatly assists groups in sharing information and ensuring that information that has already been shared does not get shared again (Mennecke, 1997).

In conclusion, it seemed that the CyberGRID did help reduce the hidden profile effect. Variances of hidden profiles were observed and indicated among the survey. The teams that frequently utilized the features of the CyberGRID (e.g. white boards, face to face meeting with avatars) and were required to mee in the CyberGRIDt, more frequently indicated on the survey and interview questions they were aware of each team members' tasks, that they never felt lost in meetings, team members responded and answered questions, and were able to provide more descriptive details about their buildings and design features. Overall, the CyberGRID enabled students to share information more effectively and efficiently compared to other virtual meeting platforms. The CyberGRID created an environment mimicking face to face team meetings alleviating some of the pains of virtual teams.

GROUP DECISION RULES RESULTS

The decision making rules for each team are as follows: CG_1 and NCG_1 followed a simple majority rule format. The team would discuss an idea and then vote on the idea. A simple majority won overall. No further discussion took place. When voting, both teams utilized the yes/no bubbles in the CyberGRID to vote. CG_2 had a unique take on the simple majority rule format. Again, ideas were presented to the group and discussed. A vote then took place, however if a team member voted no, they had to give justification as to why they voted no. The CyberGRID influenced the style of group decision making rules being made in two ways, through the yes/no bubbles and its mimicry of face to face meetings. By just having the yes/no bubbles as an option it nudged the teams using the CyberGRID to utilize the bubbles. Since their choices were limited to just "yes" and "no", majority rule became the default option to use. The CyberGRID also influences teams to use majority rules through its mimicry of a face to face meeting. Based on the interviews, CG_1, CG_2, and NCG_1 were more likely to use a majority rule format to ensure all team members were satisfied and everyone's voice was heard. During the interviews, when probing why the used majority rule, CG_1 explained, "*during our first meeting we used the yes/no bubbles to vote on a meeting time. We continued to use them through the project. We thought that's what they were there for, for voting*." CyberGRID became the default rule to use of this group, which was also observed. By far the most unique format of decisions making was found in NCG_2, which was a form of delegation. The team very early in the project decided Washington State University (WSU) would make all of the key decisions since ultimately, they held control over the design because they were in charge of the Building Information Modeling (BIM) part of the project. Ideas were presented to WSU along with the literature and justification behind these ideas was also shared. Some of the ideas proposed included implementing a green roof, bio-walls, and other sustainable features to reduce the energy load of the building as well as reduce the life cycle costs. WSU would then decide whether or not to accept the ideas and or changes to the design. Not surprisingly, this led to many arguments over the course of the project and over time the Virginia Tech students felt like they had less and less control over the project.

The retrofit and bio-inspiration required each team member with unique information not only to share their information abut also to voice their opinion in the group. Based on prior research, the most effective form of group decision making for these type of complex decision with distributed information is majority rule (Hastie et al., 2005). Per our original hypothesis, we thought that the CyberGRID would make these group decisions rules more pronounced and the teams that met in the CyberGRID would, as a result, make more effective decisions. After observing and interviewing each team, it does seem that our hypothesis proved true and that the teams that met in the CyberGRID (CG_1, CG_2, and NCG_1) used a form of majority rule which led to better decision and less conflict. It is worth noting however that some of these teams, CG_1, CG_2, and NCG_1, utilized the majority rule in a different way. While CG_1 and NCG_1 used the basic majority rule format, CG_2 used a modified majority rule where if you voted no you had to give justification as to why you voted no. The team that did not meet in the CyberGRID (NCG_2) did not use the most effective decision rule which ultimately led to more conflicts.

With the teams working from the same base models, similar retrofits were expected. Table 5 shows the Bio-inspiration and building retrofits implemented in each team's final report. Green roofs and rain water collection were prevalent across the designs. More important than "what" retrofits were selected, the process of "how" teams selected and evaluated retrofits options is the focal point of this study. The similarities between the building retrofits selected, assisted in our ability to compare the impact the CyberGRID had on team's selection process. The use of the CyberGRID appears to have helped CG_1 and CG_2 consider the bio-inspiration and retrofits in a more systematic process. CG_1 and CG_2 were observed using the white boards in the CyberGRID throughout the semester presenting and sharing ideas. CG_2 would even take turns drawing on the boards to further illustrate their point of view to their team members. The process and use of the tools within the CyberGRID were also evident in their final reports. CG_1 and CG_2 provided reports with more design details and schematics of their buildings than NCG_1 and NCG_2. In summary, the teams observed and interviewed not just required to meet in the CyberGRID but utilizing all of the intended features effectively shared more information with increasing collaboration and this was evident in their final design reports.

Table 5: Team designs features represented in final reports

TEAM	**BIO-ISPIRATION & BUILDING RETROFITS**
CG_1	• Palm leaf umbrella roof – water collection, shading • Simplified termite mound stack effect ventilation – thermal comfort
NCG_1	• Aspen tree structural system- shading, green roof, daylighting, rain water collection, solar panels

CG_2	• Bee colony variable refrigerant flow heat pumps - HVAC • Heliotropic PV tracking – solar generation • Rainwater collection – water management and filtration
NCG_2	• Forest canopy green roof – rain water collection, heat absorption, dynamic daylighting

CONCLUSION

With technology advancing work, virtual design groups are more and more common place within the construction industry. More research is needed to understand the dynamics of these teams and the influence of technology. Software mediums that enable more natural environments mimicking face to face meetings and with features that enable voting and provide opportunities to communicate around a boundary object appears to reduce hidden profiles and enable more democratic decision making processes. The CyberGRID is just one medium that begins to address some of the problems of virtual teams and tries to mitigate them by making the teams act like face to face teams. Through our research, we show that the CyberGRID helps to reduce the hidden profiles effect, however it does not appear to reduce the common knowledge effect. The teams that used the CyberGRID seemed to have worked better as a team as compared the group that did not use the CyberGRID as well as create a better design of their building. The CyberGRID also led to teams defaulting to using the most effective decision rule, majority rule. The teams that used the voting mechanisms had less internal group arguments during the observation and interviews. The team that did not use the CyberGRID used a unique decision rule, which previous literature suggests leads to bias or errors in decision making. These errors were noted in the observations, as well. The team that did not use the CyberGRID at all was also the least effective and had more problems than the other teams. Overall, the CyberGRID appears to help build trust through improved communication and ability to share information and assists teams in conducting themselves more like a in person team rather than a virtual one. Future research into how to reduce the hidden profile effect as well as how to begin to reduce the common knowledge effect is needed.

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APPENDIX

OBSERVATION AND INTERVIEW QUESTIONS

1. General observations/notes
2. Was the critical information shared? (e.g. did VT share LCA numbers to the group)

    a. Was it shared and did everyone understand it?
    b. How was it shared?
3. Did they use the features in the CyberGRID? Which ones?
4. How did the teams make a decision?
5. What information was shared locally but not globally?
6. Was there an agenda? Is the group sticking to the agenda? Was the agenda useful or just ignored?
7. Did any of the groups explain content/information/knowledge not known previously by the global group?
8. How did they identify problems in their design?
9. Was everyone involved in the discussion? Did someone dominate the discussion?
10. Was information repeated frequently? If yes, what kind of information?
11. Were erros/flaws/problems in the design detected? If yes, how were errors/flaws/problems in design detected?
12. Any Questions you developed during the Observation period

INTERVIEW QUESTIONS

1. What purpose did the CybergGRID provide you this week?
2. Was everyone involved in the discussion? Did someone dominate the discussion?
3. What do you feel is the critical information needed to progress your design? Was this information discussed by the group?
4. Was that information shared properly? Did you understand the information?
5. How did your team make a decision? (Majority rule? Loudest Person?)
6. How often did your group discuss information that everyone knew already?
7. How often was information repeated?
8. Other Technology used this week