LUMENHAUS: USES AND BENEFITS OF ICT FOR DESIGN-BUILD EDUCATIONAL ENVIRONMENTS

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ABSTRACT

By many accounts, American classrooms are not using the most effective means to properly educate and train young graduates and professionals. Common goals involve educational achievement and therefore market advantage for students, with a wide variety of proposed solutions. Among the many solutions, technology in the classroom environment has been touted as one route for translating academic goals to the market. Education in the Architecture, Engineering and Construction (AEC) industry is no different: a rise in industry and classroom technology, paired with enrollment, justifies the need to re-focus solutions from technology to provide for the academic and market needs in the built environment. The recent Virginia Tech 2009 Solar Decathlon Competition (VTSD), named lumenHAUS, offered an ideal setting for better understanding effective uses of technology in the translation of these AEC goals. VTSD was a student-led, integrated classroom environment incorporating students of all disciplines in the design and construction of an energy-efficient home. Information and communication technologies (ICT) played a major role in the educational and competitive efforts. This paper aims to describe academic uses and benefits of ICT for the modern AEC classroom through: 1) presenting common goals of the traditional AEC educational environment to those of the 2009 Solar Decathlon competition and Virginia Tech's design-build educational environment, 2) presenting various forms of ICT used to accomplish these goals and 3) discussing broad outcomes of applications for incorporated technologies across the design-build process.

Keywords: IT Supported Architectural and Engineering Design, Communication and Collaboration Technologies, Model Based Management Tools and Systems, Building Information Modeling

1. INTRODUCTION

By many accounts, American classrooms are not using the most effective means to properly educate and train young graduates and professionals (Christensen et al. 2008). Common goals involve educational achievement and competitive advantage for students, with a wide variety of proposed solutions. Among the many solutions, technology in the classroom environment has been touted as one route for translating academic goals to the market (Casey 2008). Education in the Architecture, Engineering and Construction (AEC) industry is no different: a rise in industry and classroom technology, paired with enrollment, justifies the need to re-focus solutions from technology to provide for the academic and market needs in the built environment.

Similarly, the AEC industry is highly fragmented and moving towards various project delivery systems that integrate client services. One of the biggest challenges to achieve this integration is the fragmented nature of our industry, though. As a result, Design Build (DB) has become an accepted form of project delivery for AEC, integrating the design and construction core competencies from concept to operations and maintenance (O&M) (Casey 2008). One reason for fragmentation in the AEC industry is the educational format imparted to Architects, Engineers and Construction students. The educational curriculum for different stakeholders of the AEC industry is focused towards specific needs of the particular profession with little or no concern to educate about the perspective of other members of the supply chain or integrate with them. Information and Communication Technologies (ICT), including software, hardware and virtual environments, offers the promise of incorporating integration-based knowledge in the core curriculum of AEC education. Aligning DB and ICT into the educational environment would seem to provide optimal tools and experience that better arms future professionals in the AEC industry.

The recent Virginia Tech 2009 Solar Decathlon Competition (VTSD), named lumenHAUS, served as an ideal setting for better understanding effective uses of technology in the translation of these AEC goals. VTSD was a student-led, integrated classroom environment incorporating students of all disciplines in the design and construction of an energy-efficient home. Information and communication technologies (ICT) played a major role in the educational and competitive efforts. This paper aims to explore academic uses and benefits of ICT for the classroom through: 1) presenting common goals of the 2009 Solar Decathlon competition, Virginia Tech's design-build educational environment and the AEC classroom, 2) presenting various forms of ICT used to accomplish these goals and 3) discussing broad outcomes of applications for incorporated technologies across the design-build process.

2. COMMON ICT GOALS

Generational Context

Prior to a discussion around the goals of ICT in the classroom is the important distinction of generational differences in collective thought, the current status of higher education and possible effects from both on the classroom setting. The current group of students passing through higher education has been termed "Millennials (Howe and Strauss 2003)." This group of students was born between the years 1981 and 2000, making their ages range from 9 to 28 years. According to Howe and Strauss (2007), these college-age students contain the following collective characteristics: they are "Special, Sheltered, Confident, Team-Oriented, Achieving, Pressured and Conventional." Millennials feel powerful in numbers. As children, they were always treated as special and important, being protected by others. They were also the most "wanted, celebrated and praised" generation in American history and therefore carry a sense of entitlement. Core values of Millenials are therefore as follows (quotes in parentheses from Howe and Strauss 2003):

1. Group Think ("Crave attention as a larger group").
2. High Purpose ("Feel a high sense of purpose to solve world problems; success is focused after college to higher societal issues").
3. Low Problem Solving Initiative ("Less prepared to solve their own problems and, within the college setting, will expect continued nurturing and protection by faculty and authority figures").
4. Social-based Confidence ("High confidence in themselves and, more importantly, in their group or generation; prefer team-based learning, leadership and rewards to self-achievement and recognition").
5. Technical Savvy ("They see the answer to world problems as science-based").
6. Multi-tasking ("Multiple tasking a way of life and carries a sense of normality for this generation").
7. Trust Authority ("See a common, central government authority as trustworthy and for their protection").

Without generational context, student-based competitions and educational goals might not have the same success as others.

2009 Solar Decathlon Goals

The U.S. Department of Energy (DOE) Solar Decathlon competition was originally held in 2002 with competitions since then being held biannually in 2005, 2007, and 2009. Since its beginning, the Solar

Decathlon competitions have included 92 multidisciplinary course curricula collegiate teams, totaling 15,000 participants. The competition is open to the public and free of charge and therefore strives mainly to connect with greater community regarding the possibilities of energy efficient design and construction. It enjoys an international reputation for success in educational programming and workforce development and, most recently, has expanded its outreach to local public workshop environments. It further challenges collegiate teams to "design, build, and operate a solar-powered home (Solar Decathlon 2009)." Each entrant home must exhibit primary characteristics of cost-effectiveness, energy-efficiency, and attractiveness, with best practice integrating affordability, consumer appeal, and design excellence with optimal energy production and maximum efficiency. The US department of energy stated the primary goals of the 2009 Solar Decathlon to be the following:

1. Educate the student participant - the "decathletes" - about the benefits of energy efficiency.
2. Raise awareness- among the general public about renewable energy
3. Commercialize solar energy technologies - enter the marketplace faster.
4. Foster collaboration - among students from different academic disciplines.
5. Promote "whole building design" approach to new construction (understanding lifecycle issues).
6. Demonstrate the potential of zero-energy homes (produce as much energy from renewable sources as they consume).

The 2009 decathlon competition was multidisciplinary and comprised of 10 separate competitions, five being subjective and five being objective. While all parts of the competition contain opportunity for ICT in the classroom, lifecycle and ZEH portions contained more opportunity for success from introducing ICT to the future workforce.

AEC Educational Contexts

Traditional design and educational environments do not effectively fit a scientific model. The iterative, exploratory nature of design tends to make the process appear redundant and sometimes without focus (versus a technical rationality of the scientific method). In architectural education, qualitative, rather than quantitative, data underpins much of university culture. Though scientific inquiry remains an effective instrument for unlocking secrets of the way things work, there is nagging doubt regarding its capacity to embrace holistic perspectives, particularly in regard to the implicit values of design. Traditional design education and research therefore navigates a line between perceived certainty of calculation and the artistic, intuitive processes that designers bring to situations. Architecture students often spend long hours in studio classrooms with much individual engagement between pupil and teacher, arguing ideas and engaging in exploration.

In contrast, traditional engineering educational environments fit the scientific model and enjoy many sources of funding, presenting challenges to the needs of a holistic process. The technical rationality of the scientific method, while normally accepted without question, sits in contrast to the iterative, exploratory nature of design. Engineering research and funding are typically larger in scale and scope than that of the Solar Decathlon, so much of the work needs to fit into existing curriculums and projects. No specific class in the engineering curriculum allots long hours a week to exploration and intuitive process, per se. In light of this, quantitative data typically underpins much of university culture. Courses cover distinct and quantifiable content with verifiable results.

At Virginia Tech, the worlds of Architecture and Engineering collide in the Department of Building Construction (BC), part of the Myers-Lawson School of Construction (MLSoC), a joint venture between Architecture and Engineering. Guiding teaching principles are elaborated in three philosophical concepts and reasons for being: Values Based Leadership, Excellence in Creative Learning Environments and Research and Integrating and Sustaining the Built Environment (Myers-Lawson School of Construction, 2007). As members of the larger construction community, students are subjected to engineering-level technical courses and also expected to engage in creative learning environments, including, but not limited to, case-based, seminar-based, project-based and studio-based integrated learning. MLSoC's goals further challenge students to address "all elements of the built environment that must come together in a unified and integrated way to provide the best value for owners and our society (Myers-Lawson School of Construction, 2007)."

AEC Educational Needs

President Obama's recent push for Science, Technology, Engineering and Mathematics (STEM) is one call for better educational models. Many believe the current United States' (US) higher educational system to be in failure, presenting significant challenges to any classroom environment (Christensen et al., 2008). US higher education systems seem to be educating fewer leaders in world thinking as well, with less and less US-educated professionals filling positions in cutting-edge companies or as university researchers (The Economist, 2007). Publications that provide solutions to AEC educational needs are often separated by discipline, though. While the authors are unaware of a comprehensive, current set of AEC educational goals, Christensen et al. (2008) discussed a universal set of teaching aspirations that align well with the interdisciplinary needs of an AEC educational model: 1) maximize human potential, 2) facilitate a vibrant, participative democracy, 3) hone skills, capabilities and attitudes that will help our economy remain prosperous and competitive and 4) nurture the understanding that people can see things differently.

lumenHAUS

While traditional AEC educational models provided a strong basis for engaging students, lumenHAUS, (the name of Virginia Tech's competition entry) was a trans-disciplinary collaboration between the College of Engineering and the College of Architecture and Urban Studies and was driven by an approach that challenged research through application. The house was meant to harness the tension created by the dualities of calculation and intuition; technological innovation and architectural expression; optimized performance and sensible materials. The team believed that the calculative world of science and engineering were indispensable while not sufficient – a solution ultimately must be beautiful as well as functional.

Development of lumenHAUS contained two distinct phases: concept development and design application. Concept development occurred mostly in isolation and in very much the traditional educational environments: architecture students worked in design studios, engineering students took courses that covered fundamentals of quantifiable systems and methods and construction students learned materiality and methods of items proposed for the home. The AEC stakeholders met weekly for two-to-three hours to argue the merits of specific ideas and decide collectively on a path forward. Students were engaged from the first year of their education, starting in spring 2006, so they would be engaged with the project over their four year university tenure, competing in the competition in the beginning of their final year. Concept development therefore took approximately three years.

In the third year, and once implementation of design ideas began, the team moved to a new headquarters and worked within a collaborative environment. The building, a research and development facility built in 1993 specifically for projects of this nature, contained one office room for desks of AEC faculty and students (see Figure One). Adjacent to the office was a covered work space, where lumenHAUS was physically built. Ideas and details collectively discovered in the office were implemented outside and vice versa.

Office Environment On-Site Environment

Figure One: Research and Development Facility

Courses related to lumenHAUS were separated into two areas: existing traditional courses and newly formed ones. Within the traditional AEC curriculum, content specific to lumenHAUS was now integrated with previous materials taught. For example, Principles of Construction I&II courses designed and built exterior mechanical room doors, exterior insulation screens and exterior decking (along with a prefabrication and manufacturing system). Each team independently helped with design, created work breakdown structures, take-offs, crew assignments and productivity rates, assigned equipment resources, created Gantt chart schedules, created Precedence Diagrams (Activity on Node), assigned costs and calculated bids for the work. Teams were then responsible for tracking actual progress and reporting on the difference, making larger conclusions regarding the industry. Teams were required as a group to produce a presentation and a digital report of their conclusions.

Independent studies specific to lumenHAUS were also developed by faculty. Students engaged in studio groups that met on the site for implementation of designs. Independent studies allowed flexibility of timing and catered to individual needs as well. The lumenHAUS team, a collective of AEC independent studies and studio courses, also met multiple times daily to implement specific portions of the design. Often, a morning meeting was used to plan tasks of the day and break out into educational sections, developed by faculty depending on daily needs. Faculty therefore needed to be able to apply vast ranges of knowledge and entertain many topics. Experts from industry were invited to speak and lead special sections on innovative techniques and technologies incorporated (often donated) in the house. Other industry leaders implemented designs, interacting with students through a design-build process.

Design-Build Process

In all, approximately 150 students, faculty, staff and industry consultants touched lumenHAUS. While traditional AEC faculty and students were at the core, 8 faculty and 30 industry consultants guided student objectives, working with 13 full-time students through all stages the building's design and construction process, from beginning to end. Core students and faculty ranged in the disciplines of departments of architecture, industrial design, building construction, landscape architecture, interior design, mechanical, structural, and electrical engineering, green engineering, materials science, power electronics, computer science, and marketing.

The complexity of products, processes and systems required in a project such as lumenHAUS was large. Improved project delivery approaches for AEC owners often reduce risk inherent in the complexity of the built environment. In a traditional delivery method, a 2002 study found that architects average 1,500 product selections and 17,000 decisions in designing the project (Liebing 2008). Design-build (DB), a newer project delivery approach, places designer and contractor concerns into a "single point responsibility," creating one service provider as opposed to multiple. Single point delivery ensures reduction in time from reduced document preparation, negotiation, changes and finishing of the project (Dorsey 1997). While begun in a traditional delivery setting, the second phase of lumenHAUS quickly became a design-build educational process from beginning to end, including: *1) Vision and Strategy (Program Planning), 2) Analysis and (Re-) Design (Schematics), 3) Development (Working Drawings), 4) Deployment (Construction) and 5) Use Management (Operations and Maintenance) of the building* (Dorsey 1997; Turk 2006). Items listed in parentheses are terms used frequently in AEC literature, while those not in parentheses are aligned with forthcoming ICT terms. Unlike traditional environments, lumenHAUS relied heavily on the use of ICT to accomplish its DB and educational goals. Technology helped students from diverse settings to work collaboratively in team-based, multidisciplinary environments, and realize goals, similar to complex professional situations.

3. lumenHAUS' ICT

ICT Ontology for Construction

Turk (2006) refers to the "applied science that studies the construction-specific issues related to processing, representation and communication of construction-specific information in humans and software" as construction informatics (CI). While CI provides construction specific terminology, this work will use the term information and communication technology (ICT) to apply the concepts of CI to the entire AEC industry. A multitude of classifications for ICT exists and therefore requires central domains for the purposes of better understanding the connection across the industry and among disciplines of lumenHAUS. Many have attempted to define and map the branches of computer integrated design and construction; from technology-based views to categorization via clustering historic and/or recent literature on the subject (Brandon and Betts, 1997; Turk and Lundgren 1999).

Top-down analyses are usually based on "first principles" and provide a multifaceted ontology. Bottom-up analyses are usually based on "programmer requirements" and provide clusters of data structures and individual applications for the development of higher level concepts. Turk (2006) collected AEC ICT into two major ontological categories: 1) "core" themes that "create knowledge" and 2) "support" themes in which "need is identified, knowledge transferred and impacts measured." The following core themes are adapted from Turk (2006) and meant to clarify uses of ICT in lumenHAUS:

1. Communication, discussion and collaboration:
    A. man–man (email, Internet, mobile platforms, chats, conferences, groupware, workflow)
    B. man–software (user interfaces, interactions, windows, mouse)
    C. software–software (software, program, data exchange)
    D. software–machine (software, program, robot, sensor)
2. Processing information: (data collection and cataloguing)
3. Creating information:
    A. analysis (analysis, finite elements, design, structural analysis, structural design evaluation, monitoring)
    B. synthesis (drafting, computer aided design, 3D modeling, cad, machine learning, formulation, prediction)
4. Managing information:
    A. represent (format, schema, ontologies, data structures, modeling, standards, IFC)
    B. publish (database, relational, document management, project website)
    C. retrieve (information retrieval, data mining, search, query, manuals)
5. Managing infrastructure:
    A. collaboration (Internet, web portal, communication)
    B. commerce (e-commerce, commerce, business)
    C. legal (legal, standard, law, warranties, codes, regulations).

The following support themes are also adapted from Turk (2006) and meant to further clarify ICT in lumenHAUS:

6. Needs assessment:
    A. roadmaps (internal surveys, roadmaps, vision statements)
    B. strategies (external surveys, strategies, plans, business, reengineering)
7. Technology transfer:
    A. best practice (best practices, knowledge transfer)
    B. education (education, teaching, learn, knowledge transfer)
    C. software development (software, program, prototype)

D. standards (standards, ISO, IFC)

8. Knowledge deployment: (applied experience, lessons learned)
9. Impact assessment:
   A. economic (results, savings, efficiencies)
   B. environmental (reduce, reuse, recycle)
   C. social (social aspect, social responsibility, social consequences, community)

ICT in lumenHAUS

ICTs used in lumenHAUS were vast and wide-ranging, though not necessarily exhaustive. Technologies included all major core themes and all major support themes of construction informatics as well as incorporated major goals of Millenials, the Solar Decathlon competition and greater academic goals. Table Two itemizes ICT used in lumenHAUS, according to the authors' opinions, based on major construction informatics domain themes (numbers refer to previously reported themes). The interest in listing ICTs along these applications is to better understand limits and strengths of ICT in future competitions or in the classroom environment that might better align with educational needs.

ICT	**ICT Major Literature Domain**	**Generational Context**	**Competition Goals**	**AEC Educational Needs**	**Design-Build Process**
Name of ICT or Common Term (all ICT housed data and transferred as digital files):	Numbers from *ICT Ontology for Construction* Section:	Numbers from *Generational Context* Section:	Numbers from *2009 Solar Decathlon Goals* Section:	Numbers from *AEC Educational Needs* section:	Numbers from *Design-Build Process* section:
COMMUNICATIONS APPLICATIONS					
Outlook, Gmail, Eudora, Etc.	Core: 1A, 1C, 5A; Support: 6A, 8	3,5,6	4	2	ALL
Database/ Ethernet	Core: 1C, 2,4B, 4C, 5A; Support: 6A, 8, 9B	1,2,4,5,6,7	1,4	2,4	ALL
Instant Messaging	Core: 1A, 1C, 5A; Support: 6A, 8	3,4,6,7	4	2	ALL
Texting/SMS	Core: 1A, 1C, 5A; Support: 6A, 8	3,4,6,7	4	2	ALL
Cell Phone	Core: 1A, 1C, 5A; Support: 6A, 8	3,4,7	4	2	ALL
Community Board (internet)	Core: 1A, 2, 3B; 5A Support: 6A, 6B, 7A, 7B, 8, 9C	1,2,4,5,6,7	1,4	2,4	1,2,3,4
Twitter	Core: 1A, 1B, 2, 3B; Support: 6A, 6B, 7A, 7B, 8, 9C	1,2,4,5,6,7	2,4	1,2,4	1,2,3,4
Facebook	Core: 1A, 1B, 2, 3B; Support: 6A, 6B, 7A, 7B, 8, 9C	1,2,4,5,6,7	2,4	1,2,4	1,2,3,4
Website/ HTML	Core: 1A, 1B, 2, 3B; 5A Support: 6A, 7B	1,4,5,6	2,3,4	2,3	1,2,4
DESIGN APPLICATIONS					
AutoCAD	Core: 1A, 1B, 1C, 1D, 2, 3A, 3B, 4A, 4C; Support: 7A, 7B	1,4,5,6	1,4,5	ALL	1,2,3,4
Sketch Up	Core: 1A, 1B, 1C, 1D, 2, 3A, 3B, 4A, 4C; Support: 7A, 7B	1,4,5,6	1,4,5	ALL	1,2,3,4
Cave (immersion)	Core: 1D, 3A, 3B, 5A, 5C; Support: 7A, 7B, 8	1,4,5,6	1,4,5	ALL	1,2,3,4
Photoshop	Core: 1B, 1C, 3B, 4A, 4B; Support: none	1,4,5,6	1	ALL	1,2,3,4
Illustrator	Core: 1B, 1C, 3B, 4A, 4B; Support: none	1,4,5,6	1	ALL	1,2,3,4
AutoCAD Mechanical	Core: 1A, 1B, 1C, 1D, 2, 3A, 3B,	1,4,5,6	1,4,5	ALL	1,2,3,4

ICT	**ICT Major Literature Domain**	**Generational Context**	**Competition Goals**	**AEC Educational Needs**	**Design-Build Process**
Name of ICT or Common Term (all ICT housed data and transferred as digital files):	Numbers from *ICT Ontology for Construction* Section:	Numbers from *Generational Context* Section:	Numbers from *2009 Solar Decathlon Goals* Section:	Numbers from *AEC Educational Needs* section:	Numbers from *Design-Build Process* section:
	4A, 4C; Support: 7A, 7B				
PV Design Pro	Core: ; Support:	1,4,5,6	1,3,4,5,6	1,3	3,4,5
Rhino	Core: 1A, 1B, 1C, 1D, 2, 3A, 3B, 4A, 4C; Support: 7A, 7B	1,4,5,6	1,4,5	ALL	1,2,3,4
Grasshopper	Core: 1A, 1B, 1C, 1D, 2, 3A, 3B, 4A, 4C; Support: 7A, 7B, 7C	1,4,5,6	1,4,6	ALL	1,2,3,4
MANAGEMENT APPLICATIONS					
IBC Code (Portable Document Format PDF)	Core: 1B, 4C, 5C; Support: 7D	1,3,7	1,4	4	2,3,4
IEC Code (PDF)	Core: 1B, 4C, 5C; Support: 7D	1,3,7	1,4	4	2,3,4
Competition Manual (PDF)	Core: 1B, 4C, 5C; Support: 7D	1,3,7	1,4	4	1,2,3,4
MS Project	Core: 1B, 2, 3B, 4A, 5A; Support: 6B, 7A,8	1,3,6	1,3,4,5	ALL	ALL
Revit	Core: 1A, 1B, 1C, 1D, 2, 3A, 3B, 4A, 4C; Support: 7A, 7B	1,4,5,6	4,5	ALL	1,2,3,4,5
MS Word	Core: ALL; Support: 6A, 6B, 7A, 7B, 8	1,3,6	1,4	1,2,4	ALL
On-Screen Take-off	Core: 1B, 2, 3A, 5B; Support: 9A	3,5,6	1,3	1	2,3,4
VT Survey	Core: 1B, 1C, 2, 3A, 4C; Support: 6A, 6B, 7A, 9C	1,2,3,4,7	4	2,4	1,2
ENERGY-BASED APPLICATIONS					
Trane Trace 7000	Core: 1B, 1D, 3A, 3B, 4A, 4B; Support: 6B, 7A, 9A, 9B	1,2,3,5,6,7	1,5,6	1,3,4	3,4,5
Energy Plus	Core: 1B, 1D, 3A, 3B, 4A, 4B, 5A; Support: 6B, 7A, 9A, 9B	1,2,3,5,6,7	1,5,6	1,3,4	3,4,5
Climate Consultant	Core: 1B, 1D, 3A, 3B, 4A, 4B, 5A; Support: 6B, 7A, 9A, 9B	1,2,3,5,6,7	1,5,6	1,3,4	3,4,5
Ecotect (Life-cycle analysis & Design)	Core: 1B, 1D, 3A, 3B, 4A, 4B, 5A; Support: 6B, 7A, 9A, 9B	1,2,3,5,6,7	1,5,6	1,3,4	ALL
Image J (Characterization of Sun Screens and lighting reflection)	Core: 1B, 1D, 3A, 3B, 4A, 4B, 5A; Support: 6B, 7A, 9A, 9B	2,5	1,2,5,6	1,3,4	2,3,4
Smart Grid Technology (Grid-tied Engineering and efficiency)	Core: 1B, 1D, 3A, 3B, 4A, 4B, 5A; Support: 6B, 7A, 9A, 9B	1,2,4,5,7	1,2,5,6	1,3,4	3,4,5
Siemens Apogee (Mechanical Design, Engineering)	Core: 1B, 1D, 3A, 3B, 4A, 4B, 5A; Support: 6B, 7A, 9A, 9B	2,5,6	1,5,6	1,3,4	3,4,5
Grid Point (Power Load-Shedding Software)	Core: 1B, 1D, 3A, 3B, 4A, 4B, 5A;	1,2,4,5,7	1,2,5,6	1,3,4	3,4,5

ICT	ICT Major Literature Domain	Generational Context	Competition Goals	AEC Educational Needs	Design-Build Process
Name of ICT or Common Term (all ICT housed data and transferred as digital files):	Numbers from *ICT Ontology for Construction* Section:	Numbers from *Generational Context* Section:	Numbers from *2009 Solar Decathlon Goals* Section:	Numbers from *AEC Educational Needs* section:	Numbers from *Design-Build Process* section:
	Support: 6B, 7A, 9A, 9B				
Siemens Remote Desktop (Remote Building Systems Controls)	Core: 1B, 1D, 3A, 3B, 4A, 4B, 5A; Support: 6B, 7A, 9A, 9B	ALL	1,5,6	1,3,4	3,4,5
Weather Station Software (Integrates to Weather Station Engineering)	Core: 1B, 1D, 3A, 3B, 4A, 4B, 5A; Support: 6B, 7A, 9A, 9B	3,4,5,6,7	1,2,5,6	1,3,4	3,4,5
Weather Master Software (Integrates internet to Weather for Homeowner on conventional display)	Core: 1B, 1D, 3A, 3B, 4A, 4B, 5A; Support: 6B, 7A, 9A, 9B	3,4,5,6,7	1,2,5,6	1,3,4	3,4,5
Appliance Dataloguers (software and hardware capturing data from appliances)	Core: 1B, 1D, 3A, 3B, 4A, 4B, 5A; Support: 6B, 7A, 9A, 9B	2,5,7	1,2,5,6	1,3,4	3,4,5
Screen Motion Control Software (Integrating Immersive environments with others)	Core: 1B, 1D, 3A, 3B, 4A, 4B, 5A; Support: 6B, 7A, 9A, 9B	2,3,5,6,7	1,5,6	1,3,4	3,4,5
RFID Communications	Core: 1D; Support: none	5,7	5,6	3	3,4,5
Watts-Up Pro-Logging (Power Monitoring Software)	Core: 1B, 1D, 3A, 3B, 4A, 4B, 5A; Support: 6B, 7A, 9A, 9B	2,5,7	1,2,5,6	1,3,4	3,4,5
Equest 6.36 (Energy Analysis of Building Systems and Life-cycle Analysis)	Core: 1B, 1D, 3A, 3B, 4A, 4B, 5A; Support: 6B, 7A, 9A, 9B	2,5	1,2,5,6	1,3,4	3,4,5

4. BROAD OUTCOMES

lumenHAUS' DB educational process attempted to reduce complexity of the traditional environment as well by including many courses, across disciplines, that paired design and construction skills in a studio learning environment. The courses aimed to combine students' technical and soft skills, through self-directed or team-based research and learning, using ICT. As a result, technology helped students to work collaboratively in team-based, multidisciplinary environments, similar to complex professional situations.

Not surprisingly, the domains of innovative technologies for software, hardware and human interaction were highly inclusive in lumenHAUS. Such inclusion across a large spectrum of technologies might be expected of state-of-the-art research, while not in construction and housing. Currently, the residential construction industry is known as laggard and reticent to adopt new technologies (Winch, 2003; Sexton and Barrett, 2004). lumenHAUS should not be heralded as success of innovation, though, as a pro-innovation bias could lead to interpreting resistance to innovation as backward and to misguided and ineffective conclusions (Koebel and McCoy 2007). Similarly, many technologies included across the domains of lumenHAUS might be innovative to the industry, but not the generation or group involved here. Innovative or not, resistant or not, lumenHAUS, as a typical home of the 2009 Solar Decathlon, speaks to the highly inclusive and fertile nature of ICT in AEC domains for the home, the competition and possible future directions in this industry.

All applications of ICT in lumenHAUS seem to be adapted to the needs of the Millenial generation. The management applications used herein would be the only area where generational goals are least included. These ICT applications are the most basic in their use and might be directed to all generations and less to the high-tech nature of Millenials. Interestingly, communication applications are not the only applications broadly directed to the goals of Millenials, but also high-tech applications.

Competition goals range for each type of application, from inclusive to less inclusive. As a broad statement, this could symbolize disconnect of Solar Decathlon goals with generational goals. More important would be the individual extremes of disconnection or connection within these goals as examples of applications that might need to refocus. Some applications are well aligned with student-based competitions, such as the Solar Decathlon, and could find significant opportunity in this relationship.

Educational goals for AEC seem most aligned with design applications of ICT. This could symbolize the successful development of products for this specific market by these companies over many years. The lack of connection with other applications could, similar to competition goals, reflect opportunity.

Finally, housing production is a complex process that spans multiple industries, including materials (raw and finished) producers, manufacturers, suppliers, land developers, engineers and architects (as well as other service providers), builders, specialty contractors, financial institutions, insurers, marketers, and consumers. All applications seem to understand the need for inclusion of all stakeholders in this process, even seeming outsiders. Whereas past differentiation among stakeholders was promoted as market strength, current thinking brings outsiders into the central process of designing and building a residential project. This thinking aligns with other research as to the benefits of outsider information for historically internal processes (Gladwell 2008; Von Hippel 2005) and the need for such information in AEC classrooms.

5. CONCLUSIONS

The recent Virginia Tech 2009 Solar Decathlon Competition (VTSD) served as an ideal setting for better understanding effective uses of technology in the translation of these AEC goals. VTSD was a student-led, integrated classroom environment incorporating students of all disciplines in the design and construction of an energy-efficient home. Information and communication technologies (ICT) played a major role in the educational and competitive efforts. This paper aimed to explore academic uses and benefits of ICT for the classroom through: 1) presenting common goals of the 2009 Solar Decathlon competition, Virginia Tech's design-build educational environment and the AEC classroom, 2) presenting various forms of ICT used to accomplish these goals and 3) discussing broad outcomes of applications for incorporated technologies across the design-build process.

Information and Communication Technologies (ICT), including software, hardware and virtual environments, offers the promise of incorporating integration-based knowledge in the core curriculum of AEC education. Aligning DB and ICT into the educational environment would seem to provide optimal tools and experience that better arms future professionals in the AEC industry. As members of the larger AEC community, students were expected to grow as individuals by learning technical and soft skills through personal interaction and technology that fosters multidisciplinary collaboration.

Future work would benefit from validation of the clustering of ICT with larger goals. Once validated as a set of data among more than the initial research team, the matrix might provide causal relationships that could further push ideas for AEC design-build use of technology in the future.

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