Building Technology Educator's Society

Volume 2021 Article 20

6-2021

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Recommended Citation
Leach, James and Nelson, Kristin (2021) "Commodity AND Delight: A Case for a Qualitative Basis for Environmental Technology Instruction," *Building Technology Educator's Society*: Vol. 2021 , Article 20.
DOI: https://doi.org/10.7275/3h07-xq91
Available at: https://scholarworks.umass.edu/btes/vol2021/iss1/20

Commodity AND Delight: A Case for a Qualitative Basis for Environmental Technology Instruction

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Introduction

Throughout history, human beings have lived in environments of sensory richness and variation. Outside of modern buildings and urbanized landscapes, the thermal, luminous, and acoustic environments of the natural world shift and change seasonally, diurnally, and from moment to moment. Established research points to links between the kind of multisensory environmental variation experienced in the natural world, and positive impacts to human physiological and psychological wellbeing. [i] [ii] [iii] Architectural thinkers, such as Banham, Heschong, and Pallasmaa long ago identified the value of designing with an awareness of the full sensory palette and embracing nuance and variation in the design of the built environment.[iv] [v] [vi] Unfortunately, as technology has increased the ability to control the interior environment, there has been a decisive move toward standardization and homogeneity. Modern design standards and comfort guidelines, and the built environments designed to meet them, permit only a very narrow acceptable range of variation in sound, light and temperature levels. Variance outside these narrow limits is considered to be, not just undesirable, but impermissible. This rigid control of the interior environment is believed to ensure *human comfort*, but leaves no room for *human delight,* resulting in environments of sensory monotony. Furthermore, this inflexible approach to design does not acknowledge the natural seasonal and diurnal shifts in the exterior environment. The spaces and buildings designed with environmental constancy as their goal thus consume large amounts of energy, have large carbon footprints, and have great negative impacts on the environment.

A more productive approach to teaching environmental technology requires a paradigm shift - away from the perception that consideration of environmental control strategies and technologies hamper design, and toward the recognition that embracing these concerns results in higher quality designed environment that surpasses comfort and constancy to better serve building occupants by creating sustainable multisensory spaces.

The authors teach in both building technology courses and design studios, and aspire for students to understand the lessons and the concerns of their respective technology courses as integral to the matter of architectural design. Moving beyond a set of technical and functional obligations, students must learn to appreciate the potential of environmental factors to inform and enrich the experience of the design. It can be difficult, however, to generate the level of engagement and enthusiasm, or to achieve the depth of inquiry in the technology course that is common in the design studio. Moreover, students often fail to utilize and apply developing technical knowledge to inform studio design work. This places many architecture programs in the position of failing to substantively meet the requirements of the NAAB 2014 Conditions for Accreditation, which states that graduates must "be able to comprehend the technical aspects of design, systems, and materials and be able to apply that comprehension to architectural solutions." [vii] With this goal of comprehension and application as a guide, the authors have spent nearly a decade working with colleagues to develop immersive exercises to bridge from the building technology curriculum to the design studio with an overt focus on elevating technical concerns to primary design drivers.

This paper proposes a pedagogical process of teaching environmental technology courses with emphasis on both quantitative and qualitative concerns. This process can by summarized as: read > experience > *analyze* > measure > *analyze* > calculate > *analyze*. This process will be illustrated and assessed through case studies of laboratory work undertaken in building technology courses. It is important, first, to contextualize the role of environmental control and environmental technology relative to the history and current state of architectural practice and education.

The Purpose of Architecture

It has long been recognized that a central function of buildings, and a primary motivation for their creation, is to moderate and control the ambient environment *with regard to the full palette of human senses.* This importance is illustrated in the earliest extant architecture text. In his De Architectura, Vitruvius describes proper orientation and exposure of rooms to the sun for purposes of luminous and thermal comfort.[viii] He addresses acoustics for theatrical design[ix] and, later recommends climate-responsive design approaches for houses located in differing regions to moderate climatic extremes in the interest of health and comfort.[x] These examples demonstrate that an awareness of the need to consider and respond to the human perception of thermal, luminous and acoustic environmental conditions in the design of buildings has been integral to the practice of architecture from its very beginnings. Reyner Banham more overtly contends that the impetus for mankind to create architecture was to "control the immediate environment" in order to create the "ease and leisure…(necessary) to flourish." [xi] Banham places environmental control and modification among the most basic and important, design concerns of the built environment. Banham indicates the importance of a multitude of sensory concerns among examples of such environmental modifications such as: "to create dryness in rainstorms, heat in winter, chill in summer, to create visual and acoustic privacy.[xii]

Contrasting the practical concerns of Vitruvius and Banham, Juhani Pallasmaa asserts that architecture's purpose is primarily psychological: "It domesticates limitless space and endless time, to be tolerated, inhabited and understood by humankind."[xiii] Nevertheless, Pallasmaa calls for an "Architecture of the Senses …(whose) timeless task…is to create embodied and lived existential metaphors that concretise and structure our being in the world… (and) enable us to place ourselves in the continuum of culture and time."[xiv] In this view, we require the built environment to address, not only the practicalities of physical wellbeing, but to provide a psychological anchor. Therefore, it is important for architects to embrace all of the senses in order to create built environments, and thus human experiences that establish our place within the almost incomprehensibly complex systems that surround everyday life.

Teaching the Architectural Design Studio: Image/Object vs. Environment/Experience

The studio methodology is used almost universally to teach architectural design in the United States. Embracing speculative investigation and hands-on learning, this approach offers unparalleled opportunities for integrated thinking, individual exploration, and open-ended inquiry. Often, however, the concerns of the studio privilege the visual sense, to the almost complete exclusion of all other senses. More problematically, the single image, fixed in time, tends to dominate studio products and studio discourse. This fixed image denies the layered complexity of experienced space within a dynamic environment, robbing the design of the potentials of, while also denying the liabilities of, the multisensory character of the world in which we build.

Pallasmaa decries this "fabricated, mass-produced and manipulated image,"[xv] declaring that the "cancerous spread of superficial architectural imagery" perpetuates a "nihilistic architecture (that) disengages and isolates the body" and thus denies an embodied multisensory experience.[xvi] He refers to the polished images found in architectural publications, or websites like ArchDaily, but the same problems dominate the primarily visual production of the traditional design studio. The focus on composed presentation boards, populated by beautifully-crafted and visually-compelling computer renderings, embraces that same superficiality, to the detriment of the other senses. In Pallasmaa's critique, "the inhumanity of contemporary architecture" is as a result of this ocularcentrism, "the negligence of the body and the senses," in favor of the solely visual.[xvii]

Teaching Building Science: Abstract/Quantitative Over Tactile/Qualitative

Under AIA Document B101, which defines the contractual relationship between architect and owner, **"**the Architect's Basic Services … (shall) include usual and customary structural, mechanical, and electrical engineering service."[xviii] In practice, however, few architects have the expertise to deliver competent structural, mechanical, and electrical engineering services on any but the simplest of projects. Thus, it is typical for architects to contract with consultant engineers to obtain this expertise. The ARE 5.0 Handbook, a document developed to help architectural interns prepare for the Architectural Registration Exam, acknowledges this fact, stating that "NCARB is aware of the responsibilities an architect may have for coordinating the activities of others involved in the design/construction process" as a "generalist working with numerous specialists."[xix] The Handbook goes on to further outline the accepted minimum capabilities that a licensed architect must possess in terms of coordinating and designing mechanical, electrical, and plumbing systems. It states that an architect must "determine the size of mechanical, electrical, and plumbing systems and components,…integrate specialty systems such as acoustics (and) lighting…(and) coordinate mechanical, electrical, plumbing…and specialty systems and technologies."[xx] Based on these criteria, it is clear that, at a minimum, an architect needs to know enough about building systems to inform, understand, and anticipate the concerns of the engineers, who will be the primary designers of the systems, and must know how to coordinate and integrate the systems into the designed whole. Under the current NAAB conditions for accreditation, condition B.6 requires that students have the "ability to demonstrate the principals of environmental systems' design…(which) must include passive and active heating and cooling, solar geometry, daylighting, passive ventilation, indoor air quality, solar systems, lighting systems, and acoustics," and condition B.9 necessitates "understanding of the basic principals and appropriate application and performance of building service systems, including lighting, mechanical, plumbing, electrical (systems.)"[xxi] It is clear that the focus of these professional and academic standards and requirements is purely technical, and no mention is made of the qualitative and experiential factors of building environments.

Engineering education, began to transition from apprenticeship to the academy in the 19th Century. Developments since the beginning of the industrial revolution, including steam engines, machine tools, electrical power, and advances in material science created the modern conception of engineering. These also informed an education which remains primarily focused on the science and calculations necessary to create and operate machines and mechanical systems with only a small portion (if any) of the curricula concerned with the experiential quality of the environments that such machines and systems create.[xxii] Most architectural environmental technology courses borrow heavily from engineering curricula, primarily mechanical and electrical engineering, with the obvious result that their focus remains on abstract mathematics, and measurable and quantifiable data. It is also common that architectural environmental controls courses, in contrast to design studios, are taught in more constrained, passive modes. Frequently these courses are structured around lectures, sometimes accompanied by a laboratory component, or including an applied project. Textbooks and coursework feature abstract problems, designing isolated components or systems to standardized environmental specifications. The result is an 'engineering light' approach to teaching architects, perpetuating an undervaluing of the sensory perceptions of building occupants. The abstract mathematics and fixed comfort standards taught in these courses are divorced from the gradient of sensory perception and delight as experienced by actual human beings. Thus, there is no framework and little opportunity for students to consider the potential of sensory phenomena to enrich spaces and inform design ideas.

Barbara Erwine notes a schism between architectural design and engineering practice in the profession. Designers focus primarily on the visual aspects of environmental design, while engineers are concerned with the other senses. She observes also that the engineer's concerns are often limited to an "analytical focus on measurable indices of safety and comfort."[xxiii] Lisa Heschong notes the tendency towards standardizing the thermal environment inside buildings through mechanical equipment "left to function independently of the overall design concept."[xxiv] Heschong advocates for orchestrating and manipulating the subtleties of the thermal environment to the desired effect as an integral part of architectural design.[xxv] Similarly, Erwine envisions the possibility of uniting the seemingly oppositional mindsets of designer and engineer, allowing "these two perspectives (to) sculpt the same space with different but complementary languages, tools and professional degrees."[xxvi] The eagerness with which the field of architecture has embraced phenomenology signals a desire among architects to engage with these more complex questions of the immersive multisensory experience, moving beyond the isolated image and the impersonal calculation. However, this interest tends to be limited to the realm of architectural theory rather than being a significant concern in architectural practice or in the design studio. Likewise, human experience is rarely a primary consideration of the typical building science course. This leaves the status quo of architectural education and practice in a situation of fragmentation between design (the visual), science (the measurable), and phenomenology (the experiential.)

A More Balanced Approach to Building Science

This paper proposes an approach to teaching environmental technology to architecture students that seeks to weave together the disparate threads of these three mindsets. This begins by developing in students a greater awareness of the qualitative and experiential aspects of luminous, thermal and acoustic sensory phenomenon. By engaging with these phenomena through detailed personal observation and inquiry, students develop sensitivity and criticality in their perception of the sensorial environment. The purpose of this focus on qualitative assessment of sensory observation is not to replace concern for quantitative data and calculation, but to provide a better context through which to comprehend it. This approach serves not only to create an intuitive foundation of understanding that compliments more advanced mathematical course material, it also enables the consideration of sensorial qualities as productive drivers for design thinking.

The course of study begins with foundational readings (Pallasmaa, Heschong, Erwine) to establish a conceptual base for further learning. Each reading is followed by direct observation and documentation of personal experience to build in students a first-person basis of understanding. These qualitative assessments of spaces and experiences are then followed by, and supplemented with, measurement and quantitative analysis. This approach creates a conceptual and experiential foundation upon which to scaffold the more abstract concepts, technical calculations and simulations commonly taught in environmental technology courses. The process (read > experience > analyze > measure > analyze > calculate > analyze) is illustrated in detail through the following case studies from environmental technology courses.

Case Study 1: A Place for Me

This project is an early laboratory project offered as part of a required, initial environmental design course. The project follows two early lectures which describe the sensory factors that influence the perception of a designed environment, the units of measurement that quantify these factors, and defines the difference between a climate and a designed environment. In this project, students are tasked with visiting a space on campus that they particularly enjoy. While there, they are to read their assignments for the day: a selection from Thermal Delight, by Lisa Heschong and a selection from The Architecture of the Well-Tempered Environment by Reyner Banham. Following the reading, the students complete a simple qualitative questionnaire, evaluating their experience and perception of the chosen space in light of the content of the readings. The questionnaire is based on a simple rating system for a range of environmental factors: temperature, relative humidity, light levels, wind speed and sound levels. Students circle descriptions for each factor, indicating whether the space offers too much, too little, or a pleasant amount of each. Following the qualitative questionnaire, students use measurement tools borrowed from the departmental Tech Tools Library to take quantitative readings for the environmental conditions of their chosen space. They compare the measured levels to industry standard charts that prescribe acceptable comfort ranges for various spaces and activities, and note whether their selected space falls within the acceptable range for each environmental factor. The assignment concludes with a written reflection. Students are asked to describe why they find their space to be delightful, and then consider the relationship of their quantitative data and their personal perception of sensory comfort compared to the prescriptive values suggested by industry standards. Students are finally asked to consider whether their qualitative evaluation privileged one environmental factor over others, and to note one way that they think the space could be made more delightful to the senses.

Student Responses:
Student Union Lobby Seating:
Light levels ranged from 2.4 fc in the back of the room to 54 fc if you sit by the windows. This means that the areas could be too dim, too bright or just right depending on where you sit. We think this is good because you can select where you sit based on your lighting preferences for studying. Surprisingly, the most popular seats are in the back sections with the least light. The temperature and relative humidity were not in the comfort zone, both slightly above. This surprised us as we as a group felt that it was very comfortable and we enjoy spending time there.
School of Architecture Conference Room, aka The Hot Box:
When we potted the measured relatvie humidity and temperature on the psychrometric chart, we discovered the Hot Box is far from being in the comfort zone. This did not necessarily surprise us because the space is called The Hot Box for a reason; however it was suprising how far from the comfort zone it actually was. To us, the space is thermally delightful in the winter, when it is generally cold outdoors. We often travel outdoors between our classes, and during that portion of the year it is nice to enter the space and warm up. The condition that could be improved is the lighting. The lighting is by spotlights, which create strong contrast in addition to generating heat. This could be fixed by substituting new light fixtures with whiter light and less harsh light conditions.
School of Architecture, Studio 202:
The data does not place us in the comfort zone. This does not surprise us because it is cold for our liking and drafty, which makes it less comfortable. It would need to be a few degrees warmer to be comfortable to sit and do schoolwork. It would be comfortable to sit on a couch under a blanket. I am mainly stationary while working in this space, so it gets cold quickly. Our favorite condition is the lighting. The space receives a lot of natural light in the afternoon during studio. With the blinds halfway down, there is nice lighting in the space. The condition of the space could be improved by fixing the windows. Many are drafty with gaps for cold air to penetrate the space. This could also be improved by adding supplemental heating, like a space heater, as a temporary solution.

Fig.1 Student Responses, Winter 2019

Outcomes

This project is one of the foundational activities of the environmental technology courses. It is intended to provide a grounding for future deeper explorations of topics with an understanding that both qualitative and quantitative methods of evaluating a space are important, and each approach has limitations. It is also intended to encourage beginning architecture students to understand the importance of first-person observation and the value of their own a critical assessments when studying and experiencing the built environment.

In their documentation for this laboratory, students often found that they over-privileged lighting and visual qualities of spaces and were willing to “work around” thermal or acoustic qualities. This is perhaps unsurprising given that each student chose a space specifically to undertake a reading task. Several students noted that the content of the readings could be readily applied when considering and analyzing their experiences of their respective spaces. A selection of student comments, included in the tables, reflect student findings from this exercise.

Case Study 2: Lighting Perception and Evaluation

This project is offered as part of a required, upper level environmental design course. In this multi-phase project, students are asked to gather data and evaluate knowledge about the qualitative and quantitative aspects of lighting design for the built environment. The initial phase is comprised of two relatively short 25 to 40 minute lecture sessions. These lectures revisit earlier lessons in the physics of light, human visual perception, and the imperial and metric units used to describe lighting levels from a quantitative basis. In addition, students are introduced to qualitative lighting measures like contrast, color rendering abilities, color temperature, glare, scalloping and hot spots. For this exercise, students document and evaluate the lighting of their classrooms in a variety of lighting control conditions, with variations to the position of operable shades, changes to the electric lighting switching controls, and alterations to room wall surface tones and reflectance using black cloth.

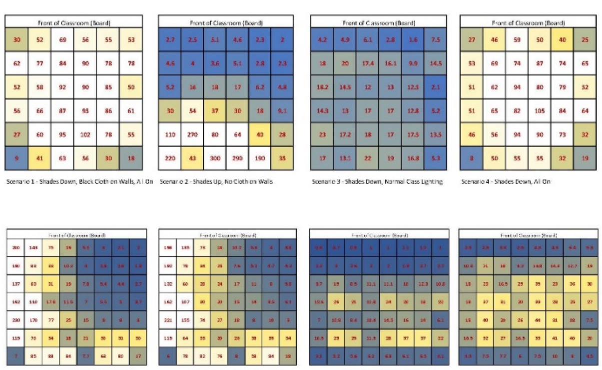

Fig.2 Lighting Map, Fall 2018 (upper) Fall 2019 (lower), Generated by Class Activity

In the initial phase of work, students collaborate to create a light map of the classroom by compiling measurements with light meters on a five-foot gridded spacing. The students pass light meters along the human grid, and call out the readings to the teaching assistant, who enters the readings into a color mapped Excel file. This method generates a simple lighting analysis grid relatively quickly. It also allows each student to directly observe the qualitative and quantitative impact to lighting levels and visual conditions, from their location in the room, as different natural and artificial lighting scenarios are created and documented.

The students then evaluate the measured light levels (in footcandles) compared to standardized lighting industry recommended light level guidelines.[xxvii] They also evaluated the more subjective phenomena observed in the various natural and electrical lighting scenarios created in the classroom. They analyzed color rendering (on their own skin and a brightly colored object) for the various lighting levels and conditions, identified the locations of scalloping and hot spots on room surfaces, evaluated contrast across the room, and identified glare on both the teaching surfaces and their own laptops and books. The example findings herein illustrate typical products of these student analyses. Note that these findings are based on the observations from two different spaces as the classroom location differed with the term.

Classroom A: Flat Floor, LED Pendants, Natural Lighting

The first teaching space, Classroom A, is a flat-floored classroom with movable rectangular tables and associated wheeled chairs that increase in height towards the back of the classroom. This room has punched vision window openings facing east and south on two walls, and exposed ceiling structure and systems. There are operable plastic mesh fabric shades on all window openings. The lighting is provided by new, linear LED pendant downlights, mounted approximately 24” from the structural deck above. These lights are controlled by individual switches which allow for on/off controls of banks of light fixtures. The banks of light fixtures are organized by distance from the front of the room. The room features historic ochre tiled walls from the floor to the horizontal mid-line, with pale, painted concrete blocks above. The ceiling, furniture and all systems are pale finishes, and the front of the room features a new, glass whiteboard along the majority of the width.

Image 1: Classroom A, top and bottom left, Classroom B, top and bottom right

Classroom B: Stepped Floor, Florescent Can and Troffer Lighting, Natural Lighting

The second teaching space, Classroom B, is a stepped, lecture hall-style classroom with fixed, continuous tables and associated sliding chairs that are adjustable in height. This room has punched vision window openings facing north and east on two walls, and a dropped acoustical ceiling with recessed luminaires. There are operable, plastic mesh fabric shades on all window openings. The lighting is provided by older, recessed florescent can fixtures, and recessed florescent troffers with three linear florescent lamps in each 2'x4' fixture. The fixtures are controlled by individual switches which allow for on/off controls. All troffer fixtures are controlled by a single switch. The can lighting is separated into two zones, with three lights near the board controlled independently from the majority of the can lighting over the student work area. The room features pale painted drywall on three walls, with a mid-tone accent wall at the back of the room. The acoustical ceiling is white, and the carpeted floor is dark gray. The built-in furniture is mid-tone oak, and the seating is upholstered in dark gray fabric. The teaching area features a large, applied plastic whiteboard along the majority of the width.

Course Year	2018	2019
Preferred	**# of Students**	**# of Students**
Quantity		
Quantity + Quality Aligned	3	5
Quantity Too Little	18	16
Quantity Too Much	4	13
Dominant Light Source		
Artificial	13	20
Natural	12	14
Least Favorite		
Quantity		
Quantity + Quality Aligned	1	1
Quantity Too Little	19	14
Quantity Too Much	5	19
Dominant Light Source		
Artificial	15	29
Natural	10	5

Fig.3 Statistics, Preferred and Least Favorite, Fall 2018

Course Year	2018	2019
Preferred	Av. Variation from Ideal 40fc, Light Office Work	Av. Variation from Ideal 40fc, Light Office Work
Quantity		
Quantity + Quality Aligned	-1	1
Quantity Too Little	-26	-20
Quantity Too Much	63	28
Dominant Light Source		
Artificial	-18	-18
Natural	0	16
Least Favorite		
Quantity		
Quantity + Quality Aligned	0	6
Quantity Too Little	-16	-24
Quantity Too Much	43	69
Dominant Light Source		
Artificial	-11	15
Natural	9	-1

Fig.4 Statistics, Preferred and Least Favorite, Fall 2019

Outcomes

The students enjoy the interactive process of taking measurements. This leads to a bit of a raucous class period in a typically restrained class. Students work in lab teams of two or three students to gather data, and they compare their responses to each other. The students tend to engage well with the evaluation portion of the exercise, taking time to write serious and considered responses. This comparison allows the students to understand, especially in Classroom B, the issues caused by the layout of the lighting fixtures - like high levels of contrast between two seats that are located relatively close together in the classroom. Samples of student writing comparing quantitative and qualitative measures are provided in the table below. These samples are typical of student response quality.

Student Responses
Scenario 1: Shades Down, Black Cloth on Walls, All On Too bright for regular tasks. It has a very sterile feel. It would be good for doing very detailed tasks or color oriented tasks. It would be good for color rendering because colors look brighter and more defined. My skin looks more washed out in this lighting. Glare is much higher and reflective surfaces are harder to focus on.
Scenario 3: Only Student Area Can Lights On We disagree with the recommended range of light for a classroom setting (40fc) and wish the lighting was more dim. We believe this was a quantity issue with the lighting. An improvement that could be made to fix the quantity of light would be to add a dimmer switch. This will allow us to control the quantity of light that could be turned up/down in the classroom.
Comparing Scenarios: Scenarios 1 and 4 (all artificial lights on) were similar, with or without the cloth, they were too bright. Scenario 2 (natural light only) was good light quality but created glare on cumputer screens. The best light came from Scenario 3 (only student area cans) which was our normal class lighting. While it was dimmer than recomended levels, it was easy on the eyes and made the projector stand out while still being workable for other activities.
Comparing Experience: My partner deemed the best lighting to be shades up, no cloth, whereas I thought shades down, black cloth on walls, all on was better. The amount of light differed between my seat and hers. For example, when the shades were up, I received more light because my seat is closer to the window, shadows formed over the paper I was writing on, but did not affect her as much. Each person should have a small lamp or lighting device close to them so they can control whether they need more or less light, especially now that classrooms have become more diverse in ages.

Fig.5 Student Responses, Fall 2019

Following Activities

The light mapping activity is followed by zonal cavity calculations by hand. The class is divided into quarters, with each respective group developing calculations for (1) a base condition, (2) a condition with a different luminaire/distribution pattern, (3) a condition with darker surfaces, and (4) a condition with a higher ceiling. Students compare their work first to groups with their own condition, to verify the accuracy of their calculation, then compare to groups assigned the other three conditions. This allows each group to understand the impact of room geometry, light distribution and luminaire selection, and surface reflectance characteristics on the luminous environment. Following this final hand exercise, students are introduced to DIALux, a digital lighting modelling and evaluation program. The class works collaboratively, using DIALux, to model the existing space. Next, each student works with a limited set of luminaires to improve the luminous environment of the classroom. Each solution is modelled in DIALux, then they are all evaluated by the entire group, examining quantitative iso curve mapping and qualitative ray-traced renderings. Faults in each solution are identified, then addressed through iterative rounds of refinement. The best solution is shared among the members of each group, and carried forward for further evaluation. The final stage of the project includes consideration of daylight contributions and lighting controls. This allows students to investigate the impact of a well-considered daylighting scheme and thoughtful controls on the energy consumption of the lighting system.

The use of spaces that the students are intimately familiar with as the subjects of these analyses is beneficial. By exercising their developing body of critical knowledge and vocabulary in assessing their own classrooms, the students are able to identify and quantify the faults in the design – many of which they are often already aware. The students are enthusiastic to explore their own ability to assess the quality of a space, then to propose improvements for those spaces and their occupants.

Case Study 3: Sound Perception and Evaluation

This project was planned as a new assignment for Spring 2019, but was not offered due to COVID measures which transitioned courses to online delivery. The project is described here to share the planned process and objectives. This project is intended to be one of the final laboratory assignments in a required, upper level environmental design course. The project is a short, in-class exercise following and building upon a series of evaluations using the classroom space as the baseline. The lighting project in the case study above is an earlier sample of the projects in this sequence. By the time of this work, students have occupied and experienced the classroom for a substantial amount of time. As in many classrooms, students tend to sit in the same seat every class period and know the strengths and weaknesses of their location well. Students begin by completing a short evaluation of the space from an acoustic perspective considering speech intelligibility, background noise, echo, and loudness while the instructor speaks from the lectern at the front of the classroom. Each student answers a brief questionnaire evaluating their own perception of several acoustic conditions at their respective locations. The students perform a hand calculation to determine the reverberation time in seconds for their classroom using the method described in Mechanical and Electrical Equipment for Buildings. [xxviii] After calculating their reverberation time, the students consult the reverberation time chart to determine whether the existing space is within the suggested guidelines and compare these quantitative findings to their personal qualitative observations.

The instructor then changes the use conditions of the room twice. In the first condition, students are asked to speak with each other socially, like they would in the cafeteria or a campus café, while considering the conditions of the room. In the second condition, the instructor plays a classical piece of music over the AV system while the students consider the conditions of the space. The activity concludes with a reflection asking students to consider the perceived strengths and weaknesses of the space regarding acoustic qualities for the different use conditions compared with the reverberation analysis. The students are tasked with developing one physical alteration of the space to improve the acoustic experience from their location in the room.

Conclusion

Qualitative sensory information can and should be regarded as complimentary and co-equal to the more traditional quantitative and mathematical information that dominates the building technologies courses in most architectural curricula. These case studies demonstrate that critical consideration and assessment of qualitative sensory phenomena can be integrated into environmental technology coursework at any level. They provide examples of how first-person experiences can serve as a foundation for more abstract and complex quantitative analysis and calculation. By interspersing experiential exercises with calculations and technical concepts, students begin to perceive the opportunities to develop designs informed by a multitude of intentions – truly integrated design. These exercises also demonstrate to students that the prescriptive and static quantitative standard is often insufficient as the sole guide for design of the multi-sensory environment experienced by building occupants.

By engendering, in the students, a greater awareness of and sensitivity to directly observable sensory information, this pedagogical approach makes technical subject matter more intuitive and accessible, while also making the direct design implications of multi-sensory consideration more obvious and apparent. By transforming the abstract technical concepts of the lecture hall into experiential realities – this approach to teaching environmental technologies begins to bridge from performance-based necessities to experiential design possibilities.

Notes or References:

[i] Mantler, Annemarie, and Logan, Alan C. "Natural Environments and Mental Health." *Advances in Integrative Medicine* 2, no. 1 (April 2019): 5–12.

[ii] Boyce, P. R. Human Factors in Lighting. Boca Raton: CRC Press, Taylor & Francis Group, 2014.

[iii] Stoops, John L. "A Possible Connection between Thermal Comfort and Health." eScholarship, University of California. Lawrence Berkeley National Laboratory, November 4, 2004. https://escholarship.org/uc/item/9j03d7kq.

[iv] Banham, Reyner. The Architecture of the Well-Tempered Environment. Chicago: University of Chicago Press, 2009.

[v] Heschong, Lisa. *Thermal Delight in Architecture*. Cambridge, MA: M.I.T. Press, 2002.

[vi] Pallasmaa, Juhani. *The Eyes of the Skin: Architecture and the Senses*. Chichester: Wiley, 2012.

[vii] The National Architectural Accrediting Board, Inc. *2014 Conditions for Accreditation.* Approved July 18, 2014.

[viii] Pollio, Vitruvius, Warren, Herbert Langford. *The Ten Books on Architecture*. Cambridge: Harvard University Press, 1914. Page 180-181.

[ix] Pollio, Vitruvius, Warren, Herbert Langford. *The Ten Books on Architecture*. Cambridge: Harvard University Press, 1914. Page 138-148.

[x] Pollio, Vitruvius, Warren, Herbert Langford. *The Ten Books on Architecture*. Cambridge: Harvard University Press, 1914. Page 170-171.

[xi] Banham, Reyner. The Architecture of the Well-Tempered Environment. Chicago: University of Chicago Press, 2009. Page 18.

[xii] Banham, Reyner. The Architecture of the Well-Tempered Environment. Chicago: University of Chicago Press, 2009. Page 18.

[xiii] Pallasmaa, Juhani. *The Eyes of the Skin: Architecture and the Senses*. Chichester: Wiley, 2012. Page 17.

[xiv] Pallasmaa, Juhani. *The Eyes of the Skin: Architecture and the Senses*. Chichester: Wiley, 2012. Page 70-71.

[xv] Pallasmaa, Juhani. *The Eyes of the Skin: Architecture and the Senses*. Chichester: Wiley, 2012. Page 21.

[xvi] Pallasmaa, Juhani. *The Eyes of the Skin: Architecture and the Senses*. Chichester: Wiley, 2012. Page 22-23.

[xvii] Pallasmaa, Juhani. *The Eyes of the Skin: Architecture and the Senses*. Chichester: Wiley, 2012. Page 17-19.

[xviii] The American Institute of Architects. *AIA Document B 101 – 2017, Standard Form of Agreement Between Owner and Architect.* https://www.aiacontracts.org/contract-documents/25141-owner-architect-agreement

[xix] National Council of Architectural Registration. *ARE 5.0 Handbook - NCARB*. Accessed October 16, 2019. https://www.ncarb.org/sites/default/files/ARE5-Handbook.pdf. Page 3.

[xx] National Council of Architectural Registration. *ARE 5.0 Handbook - NCARB*. Accessed October 16, 2019. https://www.ncarb.org/sites/default/files/ARE5-Handbook.pdf. Page 17

[xxi] The National Architectural Accrediting Board, Inc. *2014 Conditions for Accreditation.* Approved July 18, 2014. Page 17.

[xxii] National Academy of Engineering, Committee on the Engineer of 2020, Committee on Engineering Education. *Educating the Engineer of 2020: Adapting Engineering Education to the New Century*. Washington, D.C.: National Academies, 2005.

[xxiii] Erwine, Barbara. *Creating Sensory Spaces: the Architecture of the Invisible*. New York ; London: Routledge, 2017. Page 2.

[xxiv] Heschong, Lisa. *Thermal Delight in Architecture*. Cambridge, MA: M.I.T. Press, 2002. Page vii.

[xxv] Heschong, Lisa. *Thermal Delight in Architecture*. Cambridge, MA: M.I.T. Press, 2002. Page vii.

[xxvi] Erwine, Barbara. *Creating Sensory Spaces: the Architecture of the Invisible*. New York ; London: Routledge, 2017. Page 3.

[xxvii]Lighting Design Lab, Energy Trust of Oregon. *Footcandle Light Guide*. Accessed October 16, 2019. https://www.lightingdesignlab.com/sites/default/files/pdf/Footcandle_Lighting%20Guide_Rev.072013.pdf

[xxviii]Grondzik, Walter, Kwok, Alison. *Mechanical and Electrical Equipment for Buildings*. John Wiley & Sons, 2015. Page 1043-1065.