KEYNOTE SPEAKER

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1 INTRODUCTION

This paper constitutes an informal, direct narrative describing my lecture at the 2nd International Conference on Convergence in Information Science, Technology and Education (CONCITEC), Federal University of Bahia (UFBA), 26 to 28 September 2019. It was an honor and a joy to present at CONCITEC 2019 and to support the efforts of Professor Barbara Coelho, whom I was delighted to meet.

When she invited to be the keynote speaker at CONCITEC, Professor Coelho requested me to present a meaningful and inspiring summary of my professional life, particularly the academic and the corporative research experiences. Throughout my presentation, I emphasized that I firmly believe that any one in that audience could be in my place in the future. I shared that it was a special honor to be there because my father was from Pernambuco and the people from "Nordeste" have a special place in my heart.

The emphasis of my talk was in demonstrating that hard work, optimism and human connectivity can lead to amazing work and life experiences. I explained that I did not have special resources when I started my studies at UFES (Federal University of Espirito Santo), in Vitoria Brazil. I wanted to communicate to the audience that the obstacles and lack of resources, that they often experience in Brazil, while discouraging, should not prevent anyone to pursue their dreams. I particularly encouraged the women in the room, as it was very inspiring to me to see a group of strong women leading that forum. I was particularly impressed at how Professor Barbara Coelho was so fierce in organizing the event.

2 ARCHITECTURAL LIGHTING DESIGN – WORK PRIOR TO MIT

The first opening slides of the presentation showed images of my architectural lighting design prior to my start at MIT, between 1996-2004. These images were a registration of my private work as a lighting designer and architect in Brazil; and then images of my projects as a lighting designer in New York City, while working at a company named "L'Observatoire International", under Herve Descottes, for 6 years. At L'Observatoire I was a project manager and the architectural lighting design projects were highly advanced ranging from sports arenas theaters, residential complexes, office spaces, etc (Figure 1). The projects were internationally located in Amsterdam, California, Florida, Hong-Kong, etc.

Figure 1 – Architectural lighting design projects done through L'Observatoire International"

3 RESEARCH WORK AT MIT

The slides following the title "research work at MIT" introduced a selection of more relevant research projects within MIT. The following sequence of slides, explained the research structure, the methods and the results, as well as the publications. During the lecture, I described not only the research and results, but also my personal experiences and challenges in each project, including how I raised the financial resources required to buy the material and to hire the people in each of the projects. I always showed that the fact that I was at the USA did not mean that things were easy.

3.1 PARAMETRIC TOOLS AND DIGITAL FABRICATION FOR THE DESIGN OF LIGHTING SYSTEMS

In this research a software named CATIA was used to generate the digital design of luminous tiles equipped with embedded LEDs. This was a research project in collaborating with Harvard University Graduate School of Design, under Professor Michelle Addington, and sponsored by Osram Sylvania.

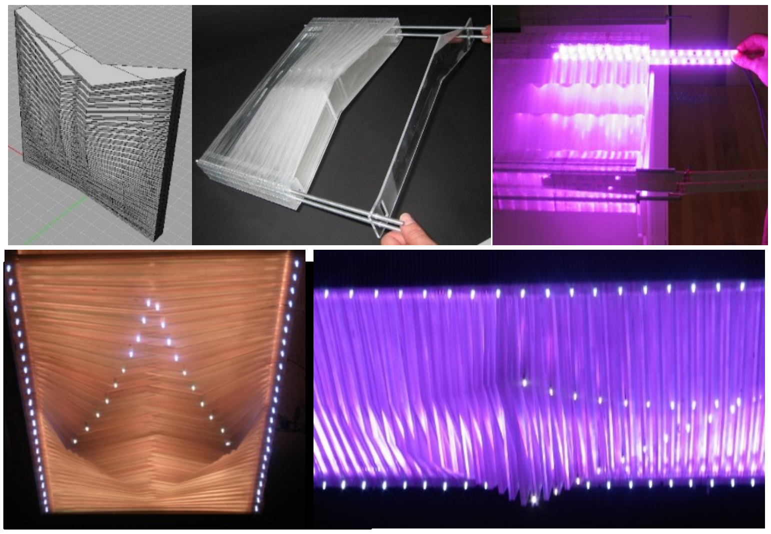
In the design process, we used the software by creating Parametric Relationships as we changed variables or parameters for the study of alternative design solutions. it is a system of input variables, output variables, and functions in a determined sequence. The parametric equations control the forming of each shape and the angle of rotation on the Generative process.

After creating the design on the software, we start the actual fabrication part of the research. Osram donated sheets of acrylic and we transferred the digital files with the modular design to the laser cutter machine in one of the MIT Media Labs Small individual modular acrylic pieces were assembled into a 3D object, then the LED strips were placed into linear openings created strategically to allow for the piece to glow uniformly (Figure 2). The unique luminous architectural tiles which can be used into ceilings or walls.

After many iteration and various different tiles assembled, we selected the best pieces and presented to Professor Addington, who gave us a financial grant for us to further develop the study. Professor Addington gave us the honor of including our pieces in her book "Smart Materials and Technologies: for the Architecture and Design Professions".

PUBLICATION:
Addington M., Schodek D. (2005). *Smart Materials and Technologies: for the Architecture and Design Professions*. Cambridge, MA: Elsevier.

Figure 2 - Small individual modular acrylic pieces were assembled into a 3D object, then the LED strips were placed into linear openings created strategically to allow for the piece to glow uniformly



3.2 LED-BASED LIGHT SOURCE HAVING DECORATIVE AND ILLUMINATION FUNCTIONS

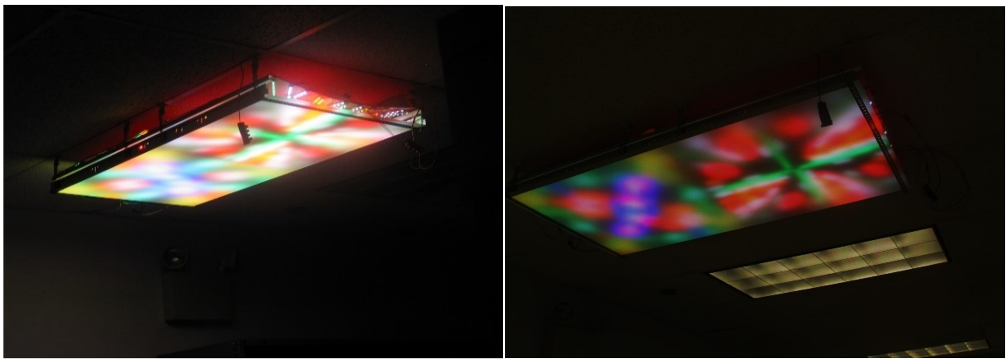
This project was the investigation of the luminous output and a control software. The main part of this research was to investigate how different colored LEDs could blend to form different types of white light. This research was done in collaboration with and sponsored by Osram Sylvania, while I was working on an internship there.

During the presentation I mentioned that this internship at Osram Sylvania happened because I found out about the name of a director online and called him up and asked for the opportunity of an internship. I emphasized that the opportunity was not there but had to be created.

The light source includes multiple colored LEDS. A digital controller energizes each colored channel of the LEDs for establishing a changing pattern of colors providing a decorative effect while simultaneously establishing a stable, continuous, white light illumination of a target area (Figure 3). This project was such an amazing experience because I had a chance to apply for a USA patent with my team and we were granted the patent. It was my first patent and it was a very exciting victory for my team at the time.

PUBLICATION:
LED-BASED LIGHT SOURCE HAVING DECORATIVE AND ILLUMINATION FUNCTIONS
Patent number: 8,829,822. Issued: September 9, 2014.
Inventors: Joseph Laski, Makarand Chipalkatti, Maria Thompson

Figure 3 – Changing pattern of the colored LED lights provide a decorative effect while simultaneously establishing a stable, continuous, white light illumination of a target area



3.3 TUNABLE LED SYSTEMS: DESIGN, TECHNOLOGY, ENERGY SAVINGS, COLORIMETRY, HUMAN FACTORS

On the following slides, I started presenting a sequence of research projects which all followed the same original principal: control strategies to manipulate different colored LEDs, in order to create white light. The investigation focused on creating "tunable" LED light systems. That means, various colored LEDs linked to a controller in independent channels, to produce all types of variations of light both colored and of white.

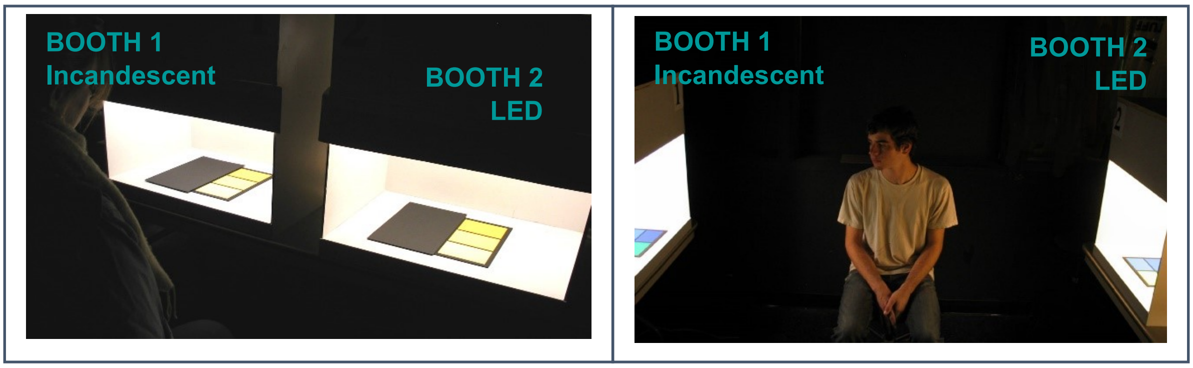
I explained to the audience that the research also focused on achieving higher levels of *efficiency*, through the manipulation of the "color rendering" of each white light. When a controller manipulates a tunable LED white light, it is altering its chromatic properties, which can be understood in two ways: the *appearance of light* (contained in two attributes: *color temperature* & *brightness*); and the *color appearance of objects* under such light (*color rendering*). The variation in color temperature implies variation in the "color" of the white light, (i.e. from yellowish to bluish white). Variation in color rendering is much less obvious but with equally important visual impact. The color rendering (CR) of a light source tells whether the colors of illuminated objects will be preserved or distorted.

The notable point in color rendering modulation is that while changing color rendering, light levels and color temperature can stay constant and hence the appearance of the light stays the same. Only the appearances of objects would change, which can be made visually subtle, or possibly "invisible". The underlining research question then was: is color rendering modulation a grand concept? Why would we want to change color rendering? The control of Red, Yellow, Green & Blue LEDs forming white light could change the way objects' colors are rendered, in order to further expand the energy efficiency of a LED lighting system, because reducing color rendering increases luminous efficiency. Modulated color rendering can potentially enable a system that dynamically shifts from 'energy saving mode' (low color rendering)' to 'quality mode' (high color rendering) according to occupancy. This technique is based a fundamental trade-off between color rendering and luminous efficacy.

The sequence of slides demonstrated the rigor and the format that a research is structured at a PhD level, at a university like MIT. I showed three series of experiments based on assessment of color perception under white light with changing color rendering. In *Phase 1* tests were carried out using laboratory booths. The slides showed the audience the three phases: Phase 1, Baseline Experiments; Phase 1A (Side-by-Side, Direct observation); Phase 1B (Opposite Side, Sequential observation) (Figure 4). Observers had to scale the VISUAL DIFFERENCE between the corresponding samples, while Color temperature & Light Levels stayed constant at 3,000 K & 280 lux. The question to the observers was: The color sample in

Booth #1 looks, < > compared to the sample in Booth #2? We examined seven LED white spectra with different color rendering, in terms of how they rendered a set of color samples to the human eye, in comparison with an incandescent bulb. Our results on this research provided us with an encouraging baseline against which encouraged to continue to investigate other viewing conditions, and a broader range of color samples.

Figure 4 - Baseline Experiments: Side-by-Side, Direct observation; Opposite Side, Sequential observation

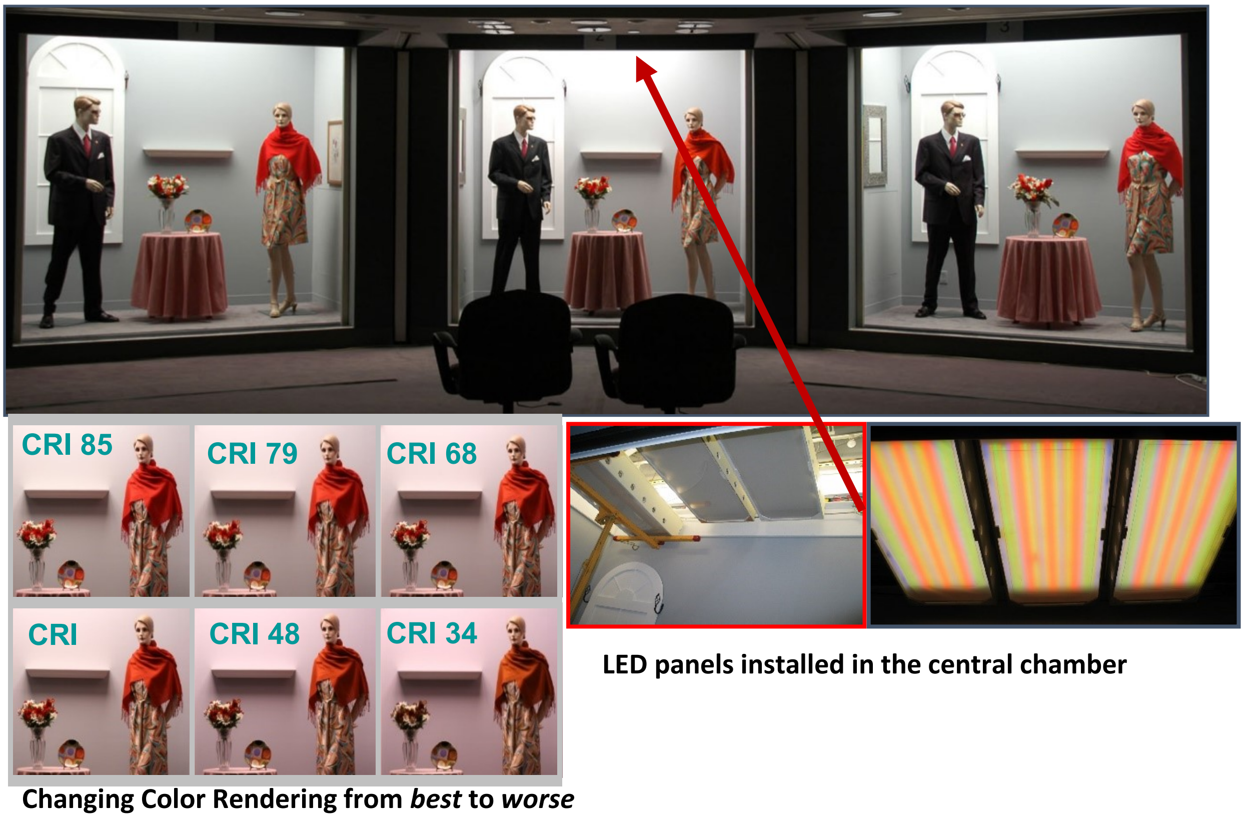


3.4 THE PHD THESIS PROJECT

The following slides specifically presented the series of experiments in my PhD thesis project. The PhD thesis research was of course the result of the various other research projects presented before. It involved intense research and experimental work but also used all the previous results as material for the thesis.

One relevant thing to be observed through the pictures is that in this phase of the thesis, I was able to use a ‘real life’ set-up with three full scale chambers and human scale mannequins (Figure 5), instead of experimental “laboratory booths” with color samples (Figure 4). The full scale chambers were important to substantiate our previous results and also to help appreciate the relationship between “real life” color distortion and color preference. So, the slides showed images of the psychophysical human factors experiment of central and peripheral vision using full scale tests. Sixty volunteers of various genders, races and ages, were asked to observe the identical scenes displayed in three different chambers and were tested in central and peripheral visual perception of the light changes. The results confirmed the fundamental hypothesis, showing that the majority of observers did not detect the color changes in their periphery while the same color changes were noticeable with direct observation.

Figure 5 – The ‘real life’ set-up with three full scale chambers and human scale mannequins



The pictures also described the work on LED panel itself. Designing and building this panel was a very a special project which was only possible with the help, collaboration and support from various different teams. At this point I emphasized to the audience how important it was for me not to give up and to continue with a positive attitude because building an LED panel was almost impossible without resources. I asked financial assistance from MIT, Osram, my department, etc. I had to build three LED panels with multiple colored LEDs and a digital controller! The panels were only possible because of many donations and also because of the help of many people who agreed to support my project. I encourage the audience to fight for resources when they believe in their ideas and projects.

PUBLICATIONS:

Thompson Maria, O'Reilly Una May. (2006). An Investigation into the Perception of Colors under Dynamic Modulation of Color Rendering in Real Life Settings. In *Proceeding of the CIE Expert Symposium in Visual Appearance*. Paris France.
Thompson Maria, O'Reilly Una-May, Levin Robert. (2007). Psychophysical Evaluations of Various Color Rendering from LED-based Architectural Lighting. *In Proceeding for the SPIE 6669, Seventh International Conference on Solid State Lighting, 66690Y.* doi:10.1117/12.746759. San Diego CA.
Thompson Maria, O'Reilly Una May. (2006). An Investigation into the Perception of Color under LED White Composite Spectra with Modulated Color Rendering. *Proceedings for the 6th Light Research Office, LRO, Symposium in Light and Color*. Orlando FL.

3.5 WORK AT OSRAM SYLVANIA AS PRINCIPAL APPLICATION SCIENTIST

I started this part of the lecture by explaining to the audience that after completing the PhD at MIT, I was offered a position as Post Doctorate at Osram Sylvania R&D Central Research and Service Laboratory, CRSL. Upon completing a year in the post-doctorate position, I was hired as a "Principal Applications Scientist". Throughout the following years at Osram the main focus of my work was in the continuation of the research started at MIT, which had already been in collaboration with the Osram Sylvania team.

3.6 SIEMENS CKI ALLIANCE: INTELLIGENT AND EFFICIENT MANAGEMENT OF ENERGY [YEAR 1]

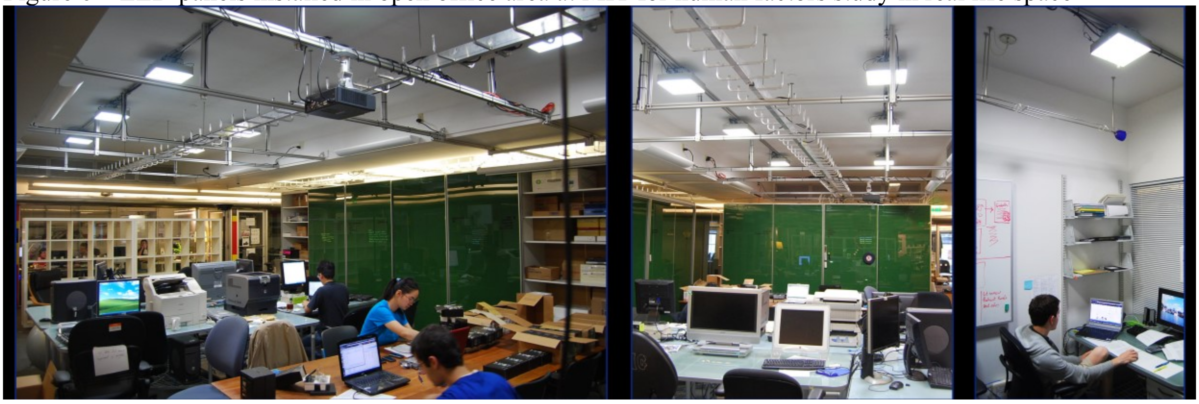
After two years at Osram, one very remarkable opportunity appeared which was to apply to a financial grant from Siemens. It was called the "*Siemens CKI Alliance*: Intelligent and Efficient Management of Energy", which was a grant offered to support research between MIT and a corporate research group. We applied with a group from MIT Media Lab (under Professor Kent Larson) to work in collaboration Osram Sylvania (my team) and we receive the grant. The Siemens CKI was a very reputable grant and we were very excited to start working together as two research teams (one academic and the other corporate) and sponsored by Siemens.

3.7 SIEMENS CKI ALLIANCE: INTELLIGENT AND EFFICIENT MANAGEMENT OF ENERGY [YEAR 2]

During the first two years of the *Siemens CKI Alliance* we continued to explore reduced color rendering to save energy but this time we also added studies using colored lighting and we specifically focused in applications for office spaces. Instead of mock ups and the full-scale chambers used before, in this research we used *real life spaces* with real people who were volunteers to participate in the research, but were truly using the space and working on their own work, while we were performing the tests.

Thirteen graduate students were asked to perform tasks in the working spaces which had computer desks arranged in an open area (Figure 6). While working, light was adjusted over 3 seconds changing color rendering. A pop-up questionnaire appeared on their screen asking what activity they were doing and whether they noticed the change. The research question was "how far CRI could be reduced before occupants noticed the change and/or found it objectionable?"

Figure 6 – LED panels installed in open office area at MIT for human factors study in real life space



3.8 SIEMENS CKI ALLIANCE: INTELLIGENT AND EFFICIENT MANAGEMENT OF ENERGY [YEAR 3]

After completion of the successful first two years with the Siemens CKI Alliance, we applied for a renewal of the contract with Siemens and to receive a new grant to continue the research. Once again, we received the grant to continue our study on "Intelligent and Efficient Management of Energy". The slides show the images of CKI research [year 3]. On this new phase, the third year of the Siemens CKI, we investigated strategic control of a tunable LED system, but in response to an *activity recognition* platform (sensors spread through the space to determine what are the *activities* the subjects are engaged in an office space), and continued to run human factors experiments to assess visual acceptability under changing lighting conditions.

Results indicate that it is possible to correlate *activities* with *sensitivity* to *spectral change*. We again looked at variations in color rendering to verify perception of subtle changes in white lighting. Beyond this investigation we also added the question of how *colored* light can be used for energy savings and as a communication medium in these commercial spaces. During year 3 of CKI our study had two main domains: (a) the lighting and sensing system (hardware & software): the design, construction and installation of a LED tunable system and its connection to a sensor network; (b) the human factors study (two visual perception experiments). In phase 1 it was observed that our human subjects were more inclined to notice the lighting changes when engaged in interactive types of activities (defined in our study as "talking" and "working") and less inclined to notice when engaged in focused tasks (defined in our study as "reading"). It was also found that color rendering changes were less noticeable to peripheral vision, which might be exploited in some types of energy savings schemes. We hoped that these results could be of some benefit to office environments, in general.

The presentation then showed phase 2 where we defined the software centered system design and sensing system, and continued the human factors for visual perception of colored lighting in the offices. Typically, the sensors cover a wide area due to their sensitivity and field of view. In our activity recognition investigation, the first step was defining coordination of sensors to minimize the number, but keep maximum coverage. From there the information is determining the most common activities in an office: *using a computer*, *working on paper* and *talking with others*. Each of these activities had a distinguishing characteristic that should allow for their classification via a decision tree.

I clarified that one of the goals of this research was to provide valid information for the lighting community about LED controllability in regards to practical implementation, as well as visual perception and comfort. Contrary to traditional lighting, LED users may have to define color and control of light, and therefore they would like to receive guidelines for implementing the controllability of LED systems. The concluding slide of this research phase, had a video demonstrating the sensors network interacting with the colored and white lighting strategies: **VIDEO: https://www.youtube.com/watch?v=TUHFe_YoZCk**

PUBLICATIONS (CKI Years 1, 2 & 3):

Thompson Maria, Spaulding Jeremy, Larson Kent, Hall Harrison (2011). Investigation of Tunable LED Lighting for General Illumination Employing Preliminary Activity Recognition Sensor Network.
Thompson Maria, Laski Joseph, Chipalkatti Makarand. *(*2011*)*. Preliminary Assessment Concerning the Practical Implementation and Visual Perception of Color Rendering Modulation for Augmented Energy Savings. *Journal of Light & Visual Environment*; ISSN:0387-8805; vol.35; no.3; page.255-266; doi: 10.2150/jlve.35.255. Japan, August, 2011.

Thompson Maria, Laski Joseph, Chipalkatti Makarand. (2010). Investigation of Visual Perception under Dynamic Color Rendering Modulation for Augmented Energy Savings. *In Proceedings of the LS12- WhiteLED3*. Eindhoven, the Netherlands.

3.9 SIEMENS CKI ALLIANCE: INTELLIGENT AND EFFICIENT MANAGEMENT OF ENERGY [YEAR 4]

In year 4 we investigated how digitally controlled lighting can follow user needs and preferences, while achieving energy savings because the brightest illumination is applied only when necessary. In this project, I showed an example application, where vacant areas of an office are illuminated by low power illumination, including colored light options, which can reduce energy consumption to 20-45% of typical full-time, full brightness, office-wide illumination. Colored light also allows communication functions and additional aesthetic design possibilities.

I presented to the audience our *context-aware* office with automatically optimized illumination, including colored illumination, based on the *detected activities* of the office users. The network of tunable LED sources, included overhead ceiling panels and desktop task lamps. C*ontext-aware* office means an office in which the lighting is "aware" of the context and activities in the room. Various office activities were detected via a multimodal network of wireless sensors (Figure 7) providing input to a central activity recognition software. The many small sensors were installed in various locations. Volunteers were invited to work in the experimental office for a day or two. We gave them a cellular phone (user interface device) which we used to collect their responses with a questionnaire (Figure 8) and also allowed them to change the lighting around their desks.

Their reactions to the automated lighting, colored lighting, and user interface were studied by conducting post-experience interviews and also through activity-triggered questions on the user interface device. Participants were asked interview questions. Overall response to the environment was positive for most participants, demonstrating reasonable optimism that the concept has value to a significant part of the population. The most enthusiastic responses were indicated by phrases such as *fun*, *stimulating*, *fancy*, *very cool*, *very pleasant*, and *enjoyed*. Color was in general more appreciated when the participant was not directly illuminated by it. Less saturated colors were more desirable in locations near to the occupant.

Energy savings were significant, about 55-80% compared to the case of uncontrolled lighting in which all overhead panels are operated continuously at the full level corresponding to occupancy. This savings is on the order of, maybe slightly higher than, typical values obtained with modern control systems based on occupancy detection alone. A long-term goal of our studies was to create an excellent working environment which provides highly optimized illumination, convenient automation and energy savings, while also providing satisfying user interfaces which enable lighting customization and personalization, in order to support worker satisfaction, mood, inspiration, productivity and creativity.

Figure 7 - Context-aware office with automatically and colored illumination, based on the *detected activities* of the office users. Office activities were detected via a multimodal network of mostly wireless sensors

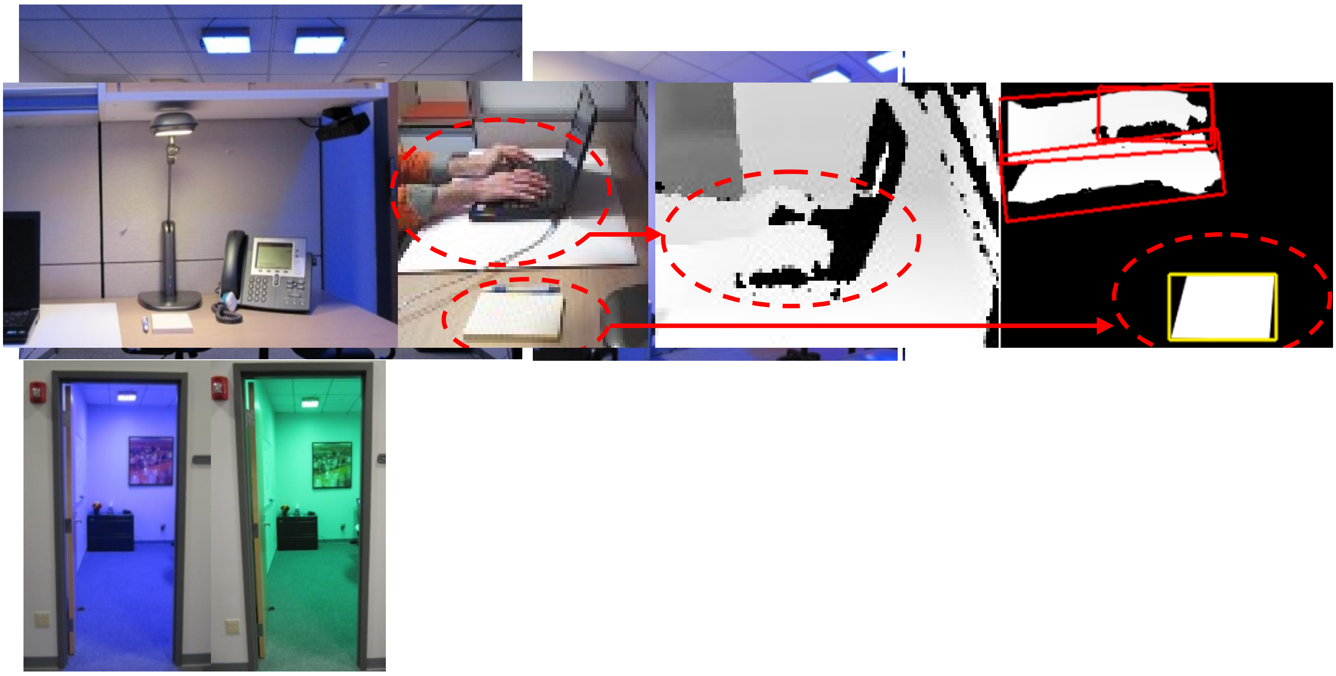
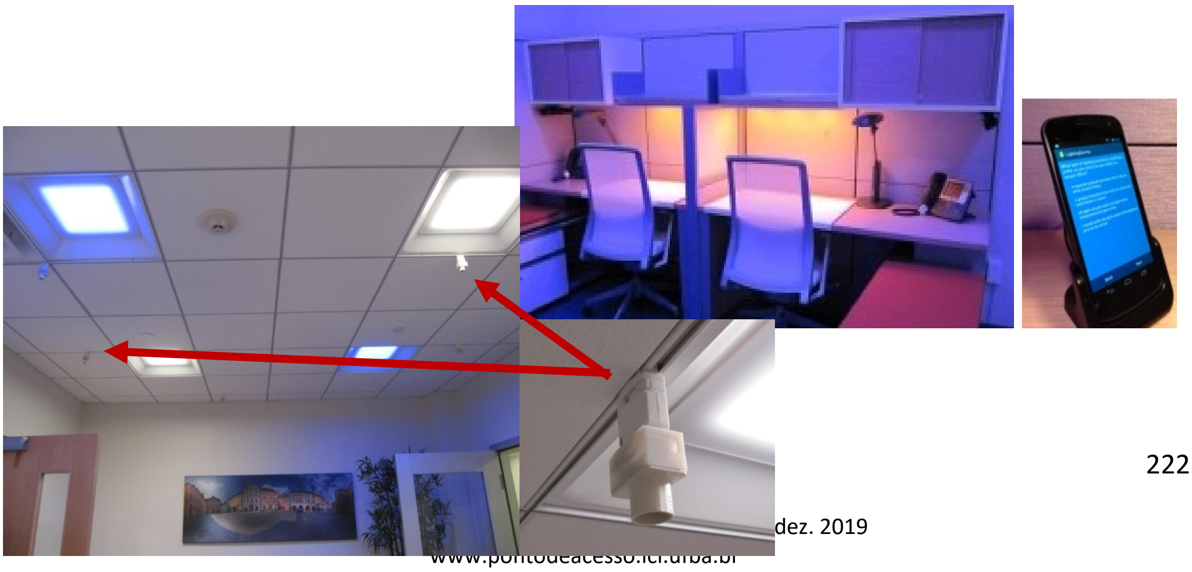


Figure 8 – The sensors installed in the ceiling lighting, and the user interface device located at the work desks, to send questionnaires to users and collect data



PUBLICATIONS:

Nancy H. Chen, Jason Nawyn, Maria Thompson, Julie Gibbs, Kent Larson (2013). Context-Aware Tunable Office Lighting Application and User Response. In *Proceedings of the SPIE 8835, LED-based Illumination Systems*, 883507 doi:10.1117/12.2021750. San Diego CA.

Jason Nawyn, Maria Thompson, Nancy Chen, Kent Larson. (2012). A Closed-Loop Feedback System for a Context-Aware Tunable Architectural Lighting Application. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, vol. 56, no. 1, 541-545. Boston MA.

4 CONCLUSION

The conclusion of my presentation was a commercial video that showed how the different technologies are becoming increasingly more digital and how the business models and speed of adoption of new technologies are changing at an unprecedented pace. I emphasized that academic research in partnership with corporate research was in the core of all my achievements, and I highly recommend to all the researchers in the audience to pursue collaborations with corporative teams. While this is a strong practice in other parts of Brazil, such as UNICAMP and UFMG, the universities in *Nordeste* receive significantly less support for corporate research and private companies.

After the conclusion of the lecture, we had a very interesting Q&A (question and answer) session, where various technical questions about research and lighting were discussed, as well as questions and comments about research in Brazil. We discussed how discouraging the current system of research in the public and private universities were and yet I did say that the best goal is to "be IRRESISTABLE" to potential partners and investors. Yes, my main message is "find partners and find investors who believe in your project". We also talked about how the different paths of technology are leading to more interactivity and interoperability of the different fields of engineering.

It has been a great joy to write this report sharing the experience during the 2nd CONCITEC at UFBA in September 2019. I hope it contributed to the understanding of what was presented during the lecture and that it will inspire those who read to continue to pursue the noble work of technology research.