NEXT GENERATION BUILDING TECHNOLOGIES: A DIFFERENT PATH TOWARDS COMMERCIALIZATION

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ABSTRACT: As the global human population expands, so do the bounds of the built environment. Advances in building technology are reactionary to the myriad of negative impacts buildings have on our global ecology: poor indoor air quality, inefficient envelope assemblies, and an unsustainable paradigm of energy use are just some of the numerous examples. There are many technological advancements that have the potential to be disruptive in the building industry, but the path towards commercialization of these technologies is often unclear and interrupted by the slow pace of product development and deployment in the construction industry. Sole source entities will not be able to develop and deploy these disruptive technologies without transdisciplinary collaboration and clear pathways for commercialization. This paper looks at an example of a next generation building technology moving to commercialization, beginning as an interdisciplinary collaboration in the academy within departments of architecture, science, and engineering. The project has become a reality by advancing the production of the system by working explicitly with architecture firms, manufacturers, and clients on real building installation projects. The technology is a modular plant wall system that improves indoor air quality (IAQ) in buildings by utilizing plants as a biomechanical filtration system that interconnects to a building's HVAC system. Potential benefits include reduced energy consumption, HVAC equipment requirements and the improved well-being and productivity of building occupants. This project could only be completed with full collaboration of industry and the academy. The proof of concept could only be developed where multiplicities of expertise can be found – biologists, designers, engineers, horticulturalists, etc. The proof of operation could only be tested in a full building scale integration where architects, contractors, manufacturers, regulatory agencies, etc. can be fully integrated into the execution and hold agency over the outcomes

KEYWORDS: Indoor Air Quality, Building Technology, Testbed

INTRODUCTION

In the classic model, buildings designed by architects have always been one-off experiments where form, material, structural innovation and/or programmatic relationships were developed and deployed. These buildings effectively became test beds to explore what are classically understood to be within the domain of the architect. However, the modern era of buildings requires significantly more consideration to include a wide range of building metrics. This new paradigm requires we instantiate new ways to create buildings and space to include the health and wellbeing of occupants. This re-emerging territory for the architect opens up the possibility for a new intellectual or innovative claim. Reyner Bahnam in his book *Architecture of the Well-Tempered Environment* offered a critique (or apology in his words) of the discipline as having evolved into such a "narrow-eyed aesthetic vision" that other agencies (plumbers and consulting engineers) would have to assume the responsibilities of maintaining building services dedicated to health and well-being. With the global pressures now weighing more wholly on the built environment there is an opportunity for architects to once again take the lead with respect to innovation within the built environment of advanced environmental systems. Models of practice and project delivery however have such a firm foothold that finding the economic territory to enable this kind of innovation is extremely difficult unless resources from outside agencies can be leveraged to advance research. Developing working relationships not only across disciplines but between enterprises (industry, services, and academy) is perhaps the only way to truly advance these issues in a holistic way.

This suggestion should not preclude the architectural endeavor from continuing to innovate in those historically significant domains where the discipline has continued to stake a claim but rather by incorporating building performance as a design challenge as well could produce similar innovations for comfort, well-being and building environment in addition to those familiar domains of inquiry.

A significant challenge with developing next generation technologies at the building scale is that ultimately the testing and characterization of these technologies is only possible at the scale and complexity of the building, rather than the confines of the lab or studio. The discipline of architecture is well equipped to understand these scalar relationships and how to navigate through those challenges once the parallels are drawn to traditional design processes: identifying the problem, developing a concept or hypothesis and outlining a working method or technique to get to the results. However, with implementing new technologies there are new workflow hurdles that must be understood. The building façade is an example of innovation occurring across disciplines on large projects and efforts in this area are better understood as it is more common to challenge this technology. Leveraging preliminary simulation models before building full-scale mock-ups and assemblies that can be empirically tested and using the results to scale the system performance within a reasonable estimate is an example of how the process can effectively advance systems. However, typically this experimentation occurs within the territory and under the financial umbrella of the façade manufacturer as they are taking both the liability and the bulk of the compensation for that assembly. The question is how can architects move beyond the skin and instantiate this kind of innovation where aesthetics may not be the primary driver, as is typically the case with the façade and drive design experimentation across the systems that fully integrate with a design challenge?

1.0 MODEL FOR NEW BUILDING TECHNOLOGIES: BUILDINGS AS TEST BEDS

1.1. Research to Practice – Commercializing Entity

There is a long-standing relationship between academia, practice, and industry sponsored projects, exploring new ideas for buildings. Evidence of this can be seen in schools of architecture across the world, where students and faculty explore discrete design problems of the built environment with varying degrees of emphasis based on program and curriculum of the institution, faculty research and pedagogical agendas, and industry support/collaboration. These studies can vary in scale and complexity from discrete explorations within a classroom, to long term projects such as the US DOE Solar Decathlon. Too often however the fruits of these endeavors are siloed to academic publications and industry headlines. To engage in translational research and move ideas into buildings requires a more complex set of relationships than asking academia to explore a particular design problem; thermal performance in building envelopes or air quality in buildings for example. Very few building owners, contractors, or architects would be willing to simply adopt some underdeveloped idea for a new building technology without some assurances of safety, functionality, etc. In short, none of the existing stakeholders would be willing to take on the liability of an untested technology.

One example model for a successful path towards commercialization that addresses this issue of liability can be found at CASE RPI, the Center for Architecture Science at Rensselaer Polytechnic Institute. CASE leverages academic programs and research agendas along with a partnership with Skidmore, Owings & Merrill LLP (SOM) to develop and propose application of new building technologies in the context of complex building projects. The model relies on initial development of ideas including fundamental research, prototyping, initial testing, characterization, and product development within the academic environment, then through the formation of a separate commercializing entity to move the technology further forward for application in buildings. The commercializing entity assumes liability for the product, takes on further design and development, then manufactures and oversees the product and projects including long term studies of installations as test-beds whenever possible

1.2. Key Stakeholders

It is a gross oversimplification to assume that any research project that can be initiated in academia and moved further with some new commercializing entity is immediately equipped to start delivering new building technologies to the building industry. The complexity of project delivery methods requires buy-in and vested interests by multiple stakeholders just to get to the point of agreeing to adopt a new building technology in a building, let alone delivering the product and long term testing and characterization to fully recognize the potential or failings of new building technologies.

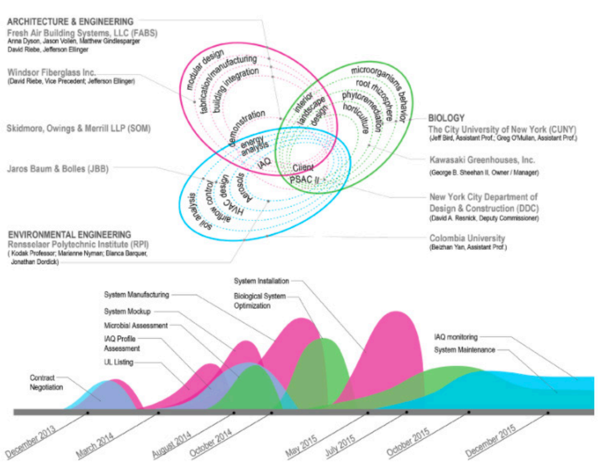

Figure 1

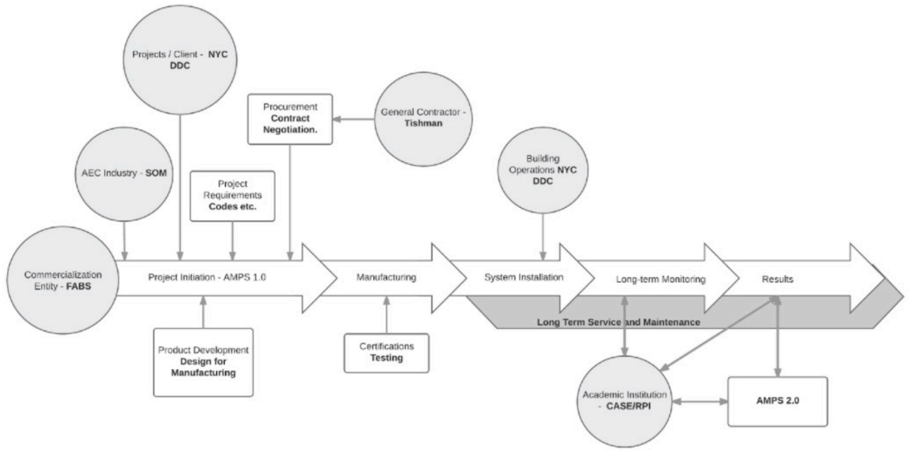

Figure 2: Organizational chart for AMP system commercialization and project delivery

Building owners and operators must be fully committed to adopting new technologies and be willing to take on the potential role of the lost leader. This critical stakeholder needs to have a vested interest in adoption of new technology, and fully support the initiative in both the short and long term. This role requires the longest commitment aside from the commercializing entity. The owner must be willing to support the integration of the technology into the building, procurement and installation of the technology, and for maximum impact the long-term monitoring and impact feedback of the technology to the project. There must be a strong relationship between the building owner and all project stakeholders to insure adequate coordination and delivery.

Architects and engineers must be willing to challenge traditional norms of project delivery and detailing to accommodate the requirements of new technologies. Contractors must be willing to install products that may be unfamiliar. Just as the building owner must be committed to integrating new technologies, architects and engineering consultants must be accommodating of new technologies and be willing to coordinate with relevant building systems. Without rigorous coordination, starting at the project outset, the potential impact of implementing new building technologies can be significantly compromised.

The commercializing entity has the challenge of coordinating all of these entities, accommodating the immediate, short term, and long term goals of delivering the project, and post-occupancy evaluation of new building systems to fully characterize potential impact at a building scale. The commercializing entity must be pro-active about managing project expectations and organizing stakeholders. Additionally, for long term characterization and understanding of potential impact, the commercializing entity must commit to the long term oversight of project installations, negotiating for long term access and monitoring of technologies.

1.3. Meeting the Needs of the Project and the Product

A large part of the interfacial role between commercializing entity and the rest of the key stakeholders draws parallels with the role of the traditional architect, with the complex problem of balancing the requirement of a particular project, and those of the new building technology/test bed. The typical architectural model that has historically driven the one-off design as a kind of “test bed” for intellectual ideas about space and planning; however, there was almost never any consideration for a post-occupancy evaluation to measure the successes or failures other than awards and publication. It is critical that specific investment be made to plan what the short and long term testing methodologies will be post-occupancy and how those efforts will be carried out. Is this work completed as an independent assessment, or through a specific sub-contract that may be connected to the technologies ongoing service and maintenance?

One critical step that the commercializing entity must take on is the identification of specific codes and regulations that allow the product to be accepted in a building such as structural, material, MEP codes, and labor regulations. To successfully deploy a test bed framework requires specific tests, certifications and coordination of architectural, structural, and MEP systems within the building to ensure that the system is allowed to operate as intended.

2.0 AMPS CASE STUDY: EXECUTION, DELIVERY, AND FEEDBACK LOOPS

2.1. The Problem – Improving Indoor Air Quality

IAQ has been identified as the fifth most important chronic health hazard nationally (Mendell, et al., 2002). Air quality in buildings can be directly related to occupant well-being and worker productivity (Clausen et al., 2011). Contemporary HVAC systems, specifically focusing on ventilation rates prescribed by ASHRAE have been the solution for most IAQ problems. Those benefits can be easily undone with dirty filters and a lack of HVAC system maintenance (Wargocki et al., 2004). The AMP System proposes a solution to the dilemma of ASHRAE standards which require potentially unhealthy outdoor air intake into building HVAC systems. By leveraging bio-remediation as a means of filtration, return air, which has limited re-usability, is revitalized and can be re-distributed. Fresh air, created from within the building could significantly offset or even replace make-up air requirements mandated by ASHRAE. Without long-term results from building scale demonstration of this concept, ASHRAE standards will be the predominant design guideline for ventilation rates and air quality in buildings.

2.2. The Solution – Building Integrated Green Wall Biofilters

The next generation building technology discussed in this paper leverages plant-based air remediation strategies in which the air cleaning capacity of plants is amplified by mechanically moving air through the root structures of the plants as it is introduced into building ventilation systems. This technology was first demonstrated by NASA biologist Bill Wolverton in the development of the NASA bio-home (Wolverton, et al., 1989). Since the NASA demonstration, variations on green wall biofiltration strategies have been developed for building integrated bio-filtration systems, most notably the Nedlaw (Darlington System) Group in Canada.

Active biofiltration systems that are fully integrated into buildings can provide commercial/institutional building types with dramatically improved indoor air quality (IAQ), while most likely reducing energy consumption and HVAC equipment requirements. The United States Department of Energy identified the Active Modular Phytoremediation System (AMPS) as a potentially energy saving system that simultaneously improves air quality in a report on potential energy saving technologies for residential HVAC systems (Goetzler, etal 2012). In addition, the biomechanical hybrid systems seeks to improve worker productivity and the general well-being of building occupants by enhancing IAQ and the spatial quality of interior environments through the introduction of large scale landscape, leveraging the concept of biophilia (Kellert & Wilson, 1995).

2.3. Active Modular Phytoremediation System (AMPS)

The Active Modular Phytoremediation System (AMPS) is a plant based wall system that leverages the entire plant systems towards the end of improving indoor air quality. The initial concepts for the AMP system were developed, tested and prototyped at CASE/RPI, leveraging the resources of academe and the potential for application in real architecture projects through the relationship with SOM. The AMP System proposes to significantly improve upon the air cleaning capacity of precedent systems by leveraging a proprietary soil matrix and a modular system designed to alleviate many of the maintenance and life-cycle challenges that current systems pose for building-integrated applications.

Plants, cultivated in a specialized growing media are placed in the air stream of a building's HVAC system on the return air side where air is cleaned and re-distributed on the supply air side of the HVAC system. Plant support systems such as water, nutrients, and lighting are integrated into the systems controls. A modular approach allows for: scalable deployment, easy installation, and more discrete control of water distribution and system maintenance.

Performance benefits of the AMP system include:

- Enhanced oxygen levels and carbon dioxide absorption,
- Significant reduction of volatile organic compounds (TVOCs); e.g., Greater than 85% single pass formaldehyde reduction demonstrated in prior tests. (Aydogan, Montoya, 2011)
- Potential reduction in outside air requirements using active phytoremediation technology
- Tremendous potential benefits to general well being associated with the introduction of natural vegetation and improved indoor air quality, including reduced illness and absenteeism.
- Introduction of bio-diverse vegetation systems that have the potential to dramatically boost human immunity
- Modular design offers scalability for a wide range of installations and reduced maintenance

The first building scale installation of the AMP system was deployed at the New York City Public Safety Answering Center II (PSAC II), developed through the partnership with SOM, the concepts of the AMP system had been developed and tested at CASE/RPI with enough confidence to develop the AMP system further into a commercialized product. In 2013, Fresh Air Building Systems LLC (FABS) was formed as the commercializing entity to design for manufacture, and fully develop the AMP system for delivery into building projects, with the first large scale installation of the AMP system being fully installed and commissioned at PSAC II in 2016.

2.4. Delivery – PSAC II Zone Scale Installation

FABS was contracted by the New York City Department of Design and Construction (DDC) to deliver and install approximately 700 square feet of AMP system modules into the new Public Safety Answering Center II in the Bronx NY which was going to be the new 911 call center for NYC. The building is a high security 24/7 facility with minimal access to natural daylight and a potentially high stress work environment. The AMP system installation is positioned on the main floor along a primary corridor, so is widely visible to everyone who works in the facility. The system includes a modular cassette system, with integrated water, nutrients and artificial lighting. The system is connected to the building's HVAC system to ensure optimal system performance and benefit to building occupants including improvements to general well being associated with the introduction of natural vegetation and improved indoor air quality (Mendell, et al., 2002) particularly in a building with limited windows and access to exterior views.

One of the major challenges of designing the system for the building was the overall size of the building versus the output capacity of the AMP system installation and the total amount of fresh air required for the building versus what can be produced. To maximize system impact, the fresh air output of the AMP system was distributed to specific rooms and the return (dirty) air from those rooms is delivered to immediately in front of the AMP system for cleaning and re-distribution. Because of the resultant HVAC system configuration, the efficacy of the system can be easily monitored and characterized post-occupancy as a test-bed.

2.5. Feedback – Maintenance and Monitoring

Once the AMP system was fully installed and operational at PSAC II, the long-term monitoring and characterization of system performance began and to date, is ongoing. Despite being designed to minimize recurring system maintenance, plant systems require some attention and maintenance. This presents a unique opportunity and mechanism to gather data about the short and long term performance of the system installation within the building. As part of regular system maintenance, FABS contracts with CASE/RPI to sample various aspects of system performance including air quality and plant health. While there is an emphasis on early efforts to collect data about the system, because there will be some recurring maintenance of the system as long as it is in existence, it presents a unique opportunity for long term testing.

CONCLUSION

The partnership and collaboration of the many stakeholders has resulted in the successful installation of a proprietary HVAC filtration system into a fully occupied building that potentially changes the way indoor air quality is understood. Research will continue through a myriad of data collections to continue to prove and improve the function of the system. The success of this project was the result of continued buy-in from all key stakeholders throughout the project. It was initiated by a unique collaboration between industry and the that enabled the incorporation of research into an occupied building. The commercializing entity (FABS) solicited buy-in from the architect and client, then leveraged lessons learned from research in academia which was supported through research grants, those not typically available to a for profit architecture firm. It is precisely this transdisciplinary arrangement, between architect, client, and academia, with access to grants and transfer of knowledge to a newly formed delivery entity that has allowed this particular project to succeed.

There have been many advances to the built environment that have been made without architects involvement but, as a discipline charged with advancing the built environment, it is imperative that architects take a leadership role to in the advancement of next generation building technologies and building integration represented by the AMPS system. The discipline of architecture fully understands the entire scope of project delivery and is positioned to facilitate the kind of coordination necessary to integrate research into building projects. However, because most project schedules do not allow for the open-ended process of scientific and experimental research it is difficult to incorporate it into the typical workflow from the inception of a contract to execute a building project. The academy is set up with the kind of infrastructures and support to take on the open-ended research within their operations. This means that the research must be initiated without a specific project driving constraints but be ready to adapt to the particular constraints of the project that emerges when the research is nearing commercialization. In order to negotiate these complexities, the suggestion here is that there needs to be more formalized relationships between academic units and architecture firms to help advance the building technologies to meet the news demands for human health and well being so as to advance outside of a single project delivery.

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