

Collaborative Research, Development, and Patent Licensing for an Energy-Saving Roofing System

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ABSTRACT

This paper describes the process and preliminary results of a collaborative research and development project for an energy-saving ventilating roofing tile system intended for market introduction. The project also served to apply an interdisciplinary design approach to the fields of architecture and civil engineering similar to that used in many high-tech industries.

I began the project seeking to develop a marketable high slope roofing system having: (a) an internal ventilation system to mitigate solar heat transfer, (b) a partial composition of recycled material, (c) durability and resistance to stresses including transport, impact, and natural forces (freeze/thaw, fire, insects, precipitation, earthquake, etc.). Interlocking roofing tile geometries were explored producing a series of contiguous channels running from eave to ridge. These geometries suggested using non-conventional roofing materials. Asst. Professor Gregor Fischer, Univ. of Hawaii at Manoa (UHM), Dept. of Civil and Environmental Engineering, who specializes in Engineered Cementitious Composites (ECC) and I discussed the project, and we decided to collaborate. We evaluated the potential of ECC for forming the roof tiles. ECC appeared promising for this application as it: (a) can be molded using common mass-production methods, (b) can be made with recycled or waste materials, (c) has a high strength-to-weight ratio, and can withstand bending stress without steel reinforcement, (d) is crack and weather resistant, (e) is fire resistive, (f) can be formed with various shapes, textures, and colors.

Computer and physical models were used to achieve a design synthesizing form, material, and function in the system. This synthesis was achieved due to our combined expertise in construction methods, building systems, material science, and structural analysis. Prototype tiles were molded of ECC, and were evaluated for dimensional tolerance and impact and bending stress resistance.

To secure intellectual property protection for the ventilating roofing system, we conducted a patent search and co-authored a Provisional Patent Application which was filed with the U.S. Patent and Trademark Office through UHM's Office of Technology Transfer and Economic Development (OTTED). An OTTED development award allowed thermal testing of the system. As of this writing, testing is starting and is scheduled to conclude in June 2005. Test results hope to show that the ventilating roofing system will reduce heat transfer from the roof to underlying interior spaces vs. existing methods. Prototype molding techniques were successful, and these appear adaptable to roof tile industry practices. Due to the promising indicators of commercial viability, OTTED has indicated interest in filing a utility patent on the invention, and negotiating patent licenses with manufacturers.

1.0 BACKGROUND

Tombesi argues that fundamental changes have occurred recently in building design and construction operational structures. He argues that increased project complexity has necessitated new non-linear processes which blur conventional distinctions between architects, consultants, contractors and suppliers. [1] Such a condition may cause architects to play a more significant role in the development of building components and systems. One result of this new role may be that buildings would be more contextually responsive. Frampton suggests “tectonic culture” may be achieved in complex modern projects by architects investing greater care in the work and collaborating with specialists using computerized network- based collaboration technologies.[2] Such arrangements may augment research and development activities occurring within typical building design and construction processes.

Architects have recently adopted Building Information Technology (BIM) to manage complexity through collaboration. BIM is based on Product Lifecycle Management (PLM), a type of computer software used by major manufacturers since the late 1970’s allowing simultaneous sharing of product data by all concerned parties including marketing, engineering, manufacturing, and suppliers. PLM allows better and faster communication, thus shortening the time to bring high value products to market. In contrast to a typical architecture project using only extant building technology, high tech product development may involve basic scientific research, applied engineering analysis, prototyping, testing, and a tight integration of physical form, user interface design, hardware, software, and manufacturing processes. Seen in this context, the present project served the dual purpose of developing a marketable building system, and to test a simple application of interdisciplinary collaboration used in high-tech industry.

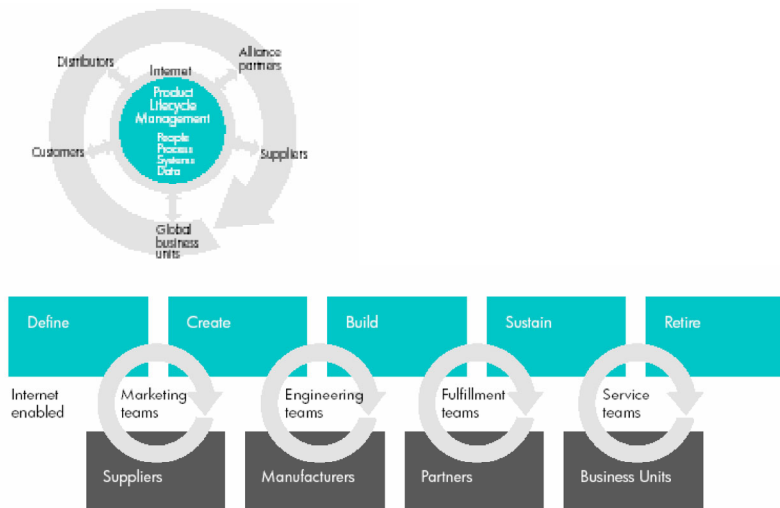


Fig. 1 (left) and Fig. 2 (right). Diagrams of PLM System as used at Hewlett-Packard Corporation (from HP corporation’s brochure entitled, “Product Lifecycle Management for the Adaptive Enterprise – The story, success, and the vision of the HP/Compaq merger”)

2.0 METHODOLOGY

2.1 Design

The ventilating roofing system project began in September of 2003 with the objective of reducing solar heat transfer. Solar roof loads contribute around 30% of the total heat gain in most houses; thus, reducing this load could have significant impact in energy consumption.[3] Common heat gain mitigation strategies work to counteract radiation, conduction, and convection effects. Reflective roofing surfaces and barriers reflect solar radiation. Insulation materials reduce convection and conduction.[4] Roof ventilation removes heat and moisture from roof spaces and assemblies. Roof shading can significantly reduce heating loads. When typical shading elements (e.g., trees, adjacent buildings) are not present, shading may be provided with a double layer roof. However, the additional cost and space requirements of double layer roofs prevent their widespread use. Therefore, a solution was sought to provide the benefits of a ventilated shaded roof in a compact space, and to dissipate heat as near the roofing surface as possible. To mitigate solar heat transfer, a first line of defense is to reflect heat from the roofing surface. A light colored roof may reflect approximately 20-25% of the solar heat energy.[5] Reflection was not pursued as a primary strategy as a reflective surface may be easily added to most roofing materials and as well may often be considered undesirable due to glare or aesthetic concerns. A second line of defense would be to quickly extract heat from the roofing material. The investigation was confined to high slope roofing. Passive ventilation was explored as this appeared the simplest and potentially most effective means of heat extraction. From the outset, the key interest in the project was to develop a cost effective alternative to common roofing systems. Therefore, using mass production techniques, low cost materials, and installation and appearance norms needed to be considered. These factors led to exploration of a modular tile roofing system incorporating contiguous ventilation channels in the assembled tiles to create a passive stack effect.

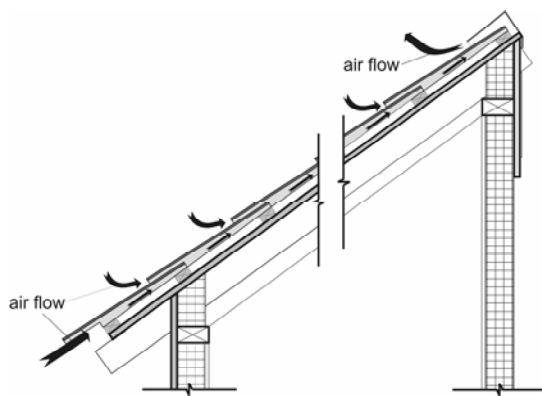


Fig. 3 Ventilating System Diagram

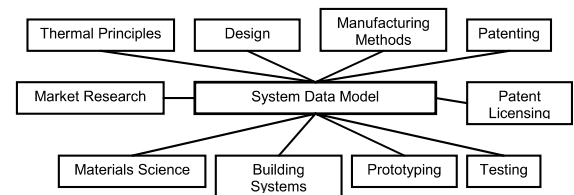


Fig. 4 Rockwood/Fischer Collaboration

Initial tile designs had forms that appeared difficult to manufacture using common shingle or tile roofing materials (e.g., clay, concrete, wood), and I thus considered using Engineered Cementitious Composites (ECC). Given my limited knowledge of ECC, I contacted Asst. Prof. Gregor Fischer of the UHM Dept. of Civil and Environmental Engineering who has particular expertise in this material. We reviewed the roofing system and agreed to collaborate on the project. Fischer and I shared an interest in developing, patenting, and licensing the system. As well, we wished to use the project to explore collaboration techniques. In contrast to the use of PLM in a large enterprise, our work occurred primarily within an academic setting involving fewer parties.

As an initial stage in the collaboration, design criteria was established for the roofing system which included providing: (a) internalized ventilation to reduce solar-induced heat transfer, (b) primary composition of recycled and waste materials, (c) durability including resistance to stress via impacts and natural forces (freeze/thaw, fire, insects, precipitation, earthquake, etc.), (d)

moldability using common mass-production techniques, (e) quick installation with moderate-skill labor (f) various shapes, textures, and colors. The primary objective was to mitigate solar heat transfer through the roofing assembly. An additional goal was to improve upon disadvantages in existing wood, concrete, and clay tile roofing systems.

2.2 Patenting

Preliminary ventilating roofing designs were developed and several appeared to meet most design criteria. The intent to market the system necessitated intellectual property protection via patenting. A U.S. patent gives the inventor the exclusive right to make, sell, or use the invention for a period of 17 years.[6] A patented invention must be novel (differs from prior art) and unobvious (synergistic functionality).[7] The patenting process began by conducting a patent search; the review of prior art uncovered extant methods for providing sloped roof ventilation: (a) installing roof tiles over battens and counterbattens, (b) using a double roof structure, (c) ventilating the space below the roof deck, (d) proprietary methods that use special hardware to create a ventilating space between the roof tiles and the roof membrane. No extant method was found in the patent search using a ventilation method similar to ours. Several methods vented the space between the roof tile and the roofing membrane, however, none accomplished this by incorporating ventilation within the roof tile itself. We then elected to co-author a Provisional Patent Application (PPA). The research was conducted in part using University facilities, necessitating invention disclosure to the UHM Office of Technology Transfer and Economic Development (OTTED), who then filed the PPA with the U.S. Patent and Trademark Office (USPTO). OTTED deemed the invention commercially viable, and offered development funds for thermal testing of the invention.

The design of the ventilating system proceeded by ensuring the stated design criteria were met while minimizing material use and maximizing overall simplicity and mass-production efficiency. In addition, novel and unobvious features needed to be retained for patenting. Using drawings, computer models, and physical models, design aspects were studied including: (a) interlocking means between adjacent tiles, (b) fastening methods of the tiles to underlying roof construction, (c) structural integrity of the tile, (d) necessary form and dimensional clearances necessary for the molding process. Initial designs were complex, being comprised of multiple pieces or having shapes difficult to mold (see Figs. 5-6). The final design is a one-piece tile (see Fig. 7).

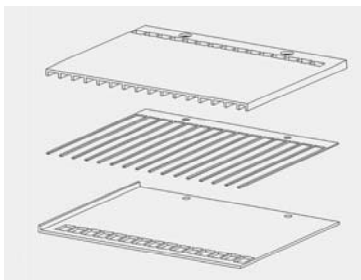


Fig. 5 Roof Tile Design "A"

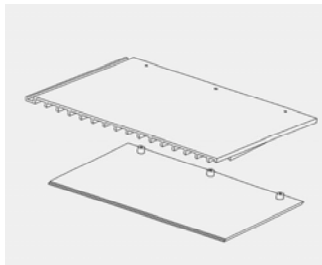


Fig. 6 Roof Tile Design "B"

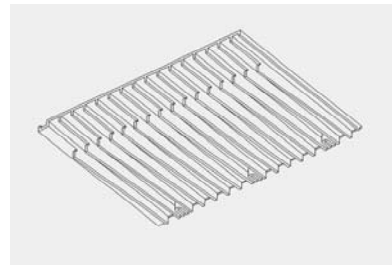


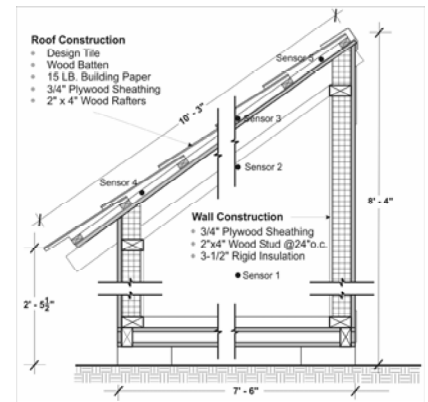
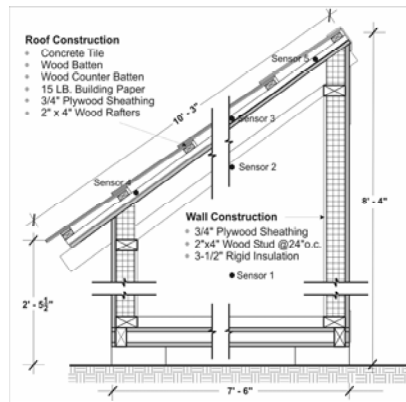
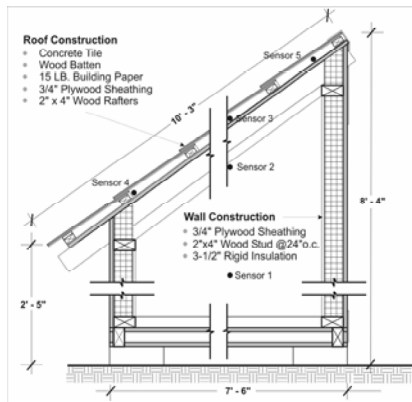
Fig. 7 Roof Tile Design "C"

2.3 Prototyping

Clay and concrete roof tiles of complex shapes are now mass-produced using two-piece molds. We reasoned our roof tile could be produced with a two-piece mold and thus be manufactured using common methods. Four different two-piece molds and associated roofing tile prototypes were developed. The first used an extruded profile for the tile such to test the basic molding process. This first casting was acceptable, having few surface flaws, no cracks, and with all features being fully formed. Practical tests on this first tile indicated it sufficiently strong to resist anticipated loads. The ECC mix contained admixtures to provide fast setting time and good flow in the mold. The second and third mold and roofing tile prototypes incorporated a more complex and intricate form. Changes in the third mold were needed to correct needed clearances and geometries. Otherwise, tile quality matched the first prototype. The fourth mold and roofing tile prototype sought to simplify the process for producing the tiles to be used for thermal testing.

2.4 Thermal Testing

Thermal testing will give data useful in marketing the invention. The experimental setup uses 3 identical huts (see Figs. 8-10 for materials, dimensions, and temperature sensor locations). Differences between the huts lie only in the roofing tile type and connection method. A first test without applied roofing materials will establish any thermal resistance variations between huts. A second test with applied roofing materials seeks to establish the effectiveness of the ventilation means in reducing thermal transfer relative to other common concrete roof tile systems. For both tests the huts will be sited on a UHM campus lawn receiving direct sun through most of the day. Huts will be aligned with the sloped roof facing due South and spaced apart to prevent huts from shading each other. For the first test, temperature data from five locations in each hut will be collected at 15 minute intervals over the course of one week. For the second test, temperature data will be collected from the same locations and using the same sampling interval, but with the overall test period extended to one month. A weather station installed near the test huts will log climatological data. Collected data will be numerically and graphically analyzed using Boxcar™



software.

Fig. 8 Hut 1 Cross Section

Fig. 9 Hut 2 Cross Section

Fig. 10 Hut 3 Cross Section

3.0 CONCLUSION

Thermal testing is not complete preventing comparison between our system and typical competitive concrete roof tile systems. However, other project objectives have been investigated sufficiently to allow evaluation. The collaborative methods worked in that Fisher's expertise in ECC materials science, molding, and structures complimented my building systems knowledge. Work was aided my computer modeling and file sharing. We achieved a simple system design by understanding and relating market forces, material, form, manufacturing methods, and natural forces. Informal structural tests indicate sufficient resistance against expected loads may be achieved in a roof tile larger than typical concrete roof tile, yet which is lighter per unit area. Hence, roof structure dead load is reduced, installation is quickened, and resistance to transport, installation, and wind/earthquake stresses is given (via ECC ductility). ECC costs slightly more than conventional concrete, however, less material is needed. Prototype molding techniques were relatively successful. Through our investigations into industry techniques, we believe our roof tiles maybe formed using standard roof tile industry two-piece molds and practices. Due to the promising indicators of commercial viability as documented in our research and outlined here, OTTED has expressed interest in filing a utility patent on our invention, and marketing the patent to manufacturers for sale or licensure.

4.0 ACKNOWLEDGEMENTS

I first thank my collaborator, Asst. Prof. Gregor Fischer, who was essential to the development of the project. I also wish to thank Asst. Prof. Stephen Meder, Director, ECS Lab, UHM, School of Architecture who donated his Lab resources. Thanks go also to UHM student research assistants who contributed to the development of the project: Mujtaba Ashan, Cori Ann Gum, Heidi Newton, Patricia Mills, and Jinghai Yang.

5.0 ENDNOTES

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