Building the 'Whole House' Greater Than the Sum of Its Parts: The Whole House and Systems Integration Focus Area Summary

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Abstract

This paper serves multiple purposes. First, it summarizes and assesses the various papers on "whole house" technologies and metrics presented in the fifth of five panels at the NSF Housing Research Agenda Workshop. Second, and perhaps most important, it poses a theoretical structure from which these papers—and all future "whole house"-related projects—might be conceived, categorized and made operational. The authors review the current social and technological context for this collective "whole house" enterprise, as well as the contexts of similar enterprises historically, to further elaborate this structure. Last, the authors suggest that a continuing dialogue between this social context and the technologies of "whole houses" must be secured in order to effect intellectual and societal change and, ultimately, to bear the technologies out.

Keywords: Industrialized Housing, Factory-Built Housing, Housing Systems, Housing Research Agenda, Systems Optimization, Whole House Production.

Holes in the "Whole House"

So, what exactly is a "whole house"? Are there unique methods for integrating the systems and components of contemporary, American detached single-family homes that suggest a breakthrough in their design or construction or, even, occupancy? These are weighty questions, and ones that have been rarely asked by the majority of homebuilders and homeowners. Yet, there are several moments in history in which these questions have been asked both by the producers of homes, researchers and manufacturers of new technologies, and policymakers attempting to address broader social and economic issues; now is one such moment.

While many research groups have loosely defined the concept of the "whole house," most of these have only either suggested broad changes in the home building industry structure, or detailed the technical mechanics of systems integration. Indeed, if any specific recommendations are provided, they only serve to enhance one function or system in a house—i.e., sub-optimization. The most recent attempt to define "whole house" methods comes from the Partnership for Advancing Technology in Housing (PATH), a public-private partnership

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organized within the US Department of Housing and Urban Development (HUD). PATH's seminal documents for establishing research agendas (or the PATH "roadmaps") suggest that the core reason for the homebuilding industry's technological inertia within any of its practices comes from its inability to advance holistic approaches to designing, constructing, and maintaining homes, or "systems thinking." (NAHB 2002)

Also defined as "systems engineering," this approach to "whole house" technological analysis implicates both an integrative framework for optimizing individual subsystems (such as heating, structure, water, etc.), but also provides the unique opportunity to reconsider the composition of these systems when studied as parts of a whole. For example, how can water and heating subsystems be conjoined optimally rather than kept as separate subsystems that require unique manufacturing processes, jurisdictional labor trades, and subsequently redundant costs and schedules for home construction? Such questions abound in a systems-approach analysis.

Looking through only technological lenses, "whole house" efforts generally start out in one of two ways. A top-down strategy is commonly employed wherein the ultimate performance of the house is determined first, thereby assuming the physical materials and systems would fall out; this strategy is evident in current discussions of industrialization in homebuilding (VPI Center for Housing Research 2000) and manufactured housing (MHRA 2003). The bottom-up approach focuses on interactions between specific systems—the logic being that a necessary component of understanding the whole picture of housing production is the understanding of how each component works, has worked historically, and could work in coordination with other housing components. A sample research project like this would be disentangling utilities from structural frames.

Unfortunately, the technical complexities of either approach are often gargantuan compared to the resources available for studying them. A top-down approach would require coming to a consensus on specific building performance traits, understanding how different physical components of a house determine or partially determine these traits, and then planning out the best design, construction, and operation; so, the trick is in the implementation. The alternate approach would involve categorizing and analyzing the thousands of materials and technologies within the dozens of systems in housing, and insuring they each was optimized under varying conditions; here, the difficulty is insuring that the forest is still seen despite the trees. Indeed, numerous scholars have described the technical difficulties in optimization efforts, and in systems approaches in general.

Additionally, there are numerous non-technical problems with using system optimization as the basis for any full scale reconsideration of practice, though it might seem to be the only reasonable catalyst for change in this otherwise sluggish technological field. This is as critical a challenge to "whole house" as the technical enterprise though it is often given scant attention. Through work in the history and sociology of technology, we know that technologies are as much social as they are technical. As such technological systems are conceived to accommodate specific social agendas, for better or worse (Bijker et al 1987; Hughes & Mayntz 1988). "Systems thinking," then, often masks much of this underlying motivation, and inaccurately predicts how specific technological products and processes will be interpreted and how they will naturally undergo change through that interpretation.

Nationally, further, projects that have focused on such far-reaching technological systems in housing have historically failed—for example, HUD's previous experience with Operation Breakthrough from 1968 to 1974 (GAO 1976). Interestingly, of the many projects set out in the PATH Roadmap for "whole house" research, PATH's various committees selected "changing the home building paradigm" as one of the first. This is certainly not a light task, as many of the traditional methods and organization of work in US homebuilding have endured for decades. Indeed, there are numerous characteristics in the industry that would require significant addressing if a paradigm were to shift. These include: American popular conceptions of housing and housing environments; affordability constraints; fragmentation among different building systems and the different parties pertinent to each; site-specific managerial processes; and lack of significant technological innovation and adoption. Any attempt to refashion the "whole house" must take these into consideration.

So, why do most approaches to "whole house" research focus on its technological composition and performance? This could be explained simply as the product of numerous current biases and contemporary trends. On the one hand, industry does not want to overly complicate a product that appears to be financially successful and are, therefore, content with fiddling with the technological pieces as long as the look, function, and location of housing remains. Research institutions—and the researchers that they have fostered—repeatedly look for the technological "fix" to societal dilemmas, on the other hand. This establishment rewards technological breakthroughs over reflective and, oftentimes, applicative inquiry. It must also be said, however, that sociological and economic studies of houses and housing have also contributed to this singular technological drive. In assuming that housing science and all of its constituent parts have less to do with contemporary housing concerns than economic and politics (especially finance, planning, and community development), social scientists have been complicit in letting technologists develop their separate agendas. This marginalization certainly leaves all parties wondering how different disciplines are even related when it comes to housing, let alone how they can jointly solve housing problems.

These broad movements surely leave us with many questions both regarding how to set out a university-based research agenda in this area, in addition to questions about its content. It was under these conditions that the "Whole House and Systems Interaction" Panel convened in February, 2004, through the auspices of the NSF Housing Research Agenda Workshop.

The Whole House focus group included participants from more diverse disciplinary backgrounds than any other Workshop panel; these included construction managers, architects, mechanical engineers, structural engineers, industrial engineers, and architectural engineers. The group had experience in materials science, process design and engineering, construction simulation, construction management, structural design, mechanical systems design, systems integration, history of technology, moisture control, building construction and architectural design to represent a fairly broad range of expertise necessary to discuss the Whole House idea.

Not surprisingly, then, the scope of papers presented there (and included in these proceedings) were similarly varied. After a cursory review, the panel leaders chose to categorize them based on a structure that encompassed the life-cycle of a house—the idea being that performance across time is one way of conceiving of the totality of a house. Specifically, this was broken out into four categories, with their respective paper authors:

- ?? Programming the Whole House: Shenton, Bronet (for Van Dessel)
- ?? Designing the Whole House: Khoshnevis, Ellis, Graham
- ?? Constructing/Manufacturing the Whole House: Beliveau, Syal
- ?? Operating the Whole House: O'Brien

In addition to the perceived linearity of this order, it soon became apparent that it was flawed. Breaking down the concept of "whole house" research into an individual house's functional existence would keep us from looking at the totality of the performance attributes demanded of a house (that is, what it does) and the plethora of technologies and systems that could satisfy that performance (or, how it does what it does). As such, we quickly reordered the papers into those describing performance attributes (and one that categorized them), and those describing systems (and one that categorized those).

- ?? Whole House Attributes: Graham, Beliveau
- ?? Categorizing Attributes: O'Brien
- ?? Whole House Systems: Khoshnevis, Van Dessel, Shenton, Ellis
- ?? Categorizing Systems: Syal

More to the point, specific questions came to mind during this reorganization that helped us conceive of the unwieldy "whole house":

- ?? Is the current housing system technically failing?
  Where and in what ways (design, material, performance, technique)?
  With which societal impacts (affordability, diffusion, market acceptance, regulations, environment, occupant health, etc.)?

- ?? What are the boundaries of the "whole" in "whole house"?
  How big is it conceptually?

- ?? How many types of approaches are there to the "whole"?
  Those that are attribute-generated like "energy efficiency," "durability," etc.?
  Or, those that are method-generated as in specific technologies or system interactions)?

- ?? Is a "revolution" or an "evolution needed in housing systems?
  Why?
  What are the indicators?
  What are the constraints?

In the panel's discussions, the first and last questions seemed to elicit the most enthusiastic responses and were a basis for much of the discussion in the focus group for the remainder of the session. The group was evenly divided on their observations regarding the first question on the current housing system; this split came about because of the different lens through which we could picture contemporary housing. Technically, the panel felt that contemporary houses are "failures" due to their cost, quality, disaster performance, moisture, mold, and durability issues. In short, there is a failure of the whole—a sub-optimization of the pieces that leads to limited integration and an inability to measure and assess performance. As such, there is a fragmented knowledge base that keeps us from accepting anything close to a perfected home.

The case against seeing the current system in failure mode, however, demonstrated a totally different understanding of homes—that is, one predicated on social and economic well-being. The high rate of homeownership, the success of housing as a wealth-building strategy, and the relative simplicity of housing systems for homeowners are all examples of how housing technology works. Despite this "success," however, many panelists suggested that the measures of success have historically and will definitely change. Not only will these social conceptions of the home change, but these will necessarily transform the techniques and technical measures of the "success" of the home.

The "revolution" or "evolution" question further opened the discussion along these societal and technical lines, with a particular focus on the core mission of the various researchers, research institutions, and this very NSF Workshop. A number of the panel participants strongly advocated a singular focus on the technologies of housing (including many of the recipients of NSF and PATH funding for technology research project) with the assumption that societal consumption would eventually be integrated. These advanced materials and technology processes primarily employed a strategy to reduce the overall number of parts needed to make a house, proposing the physical integration of subsystems within the panel or contour-crafted superstructures making up the house.

The discussion of specific technology revolutions was balanced by a discussion of the attributes of the whole house and the evolution or use of design methods to achieve them. Sub-optimization of systems, contracts and materials was seen as a significant obstacle to achieving the whole house. This focused the discussion on the subject of integration of specific systems on the one-hand, or defining and measuring their performance on the other. The attribute discussion ranged from specific disaster performance to the impacts of the house on natural and public resources and led to a discussion of the house as an assistive device, diagnosing and healing itself, cleaning itself, minimizing the spread of infection between its occupants. This attribute discussion drew towards a conclusion that a primary attribute of the revolutionary whole house should be its ability to support the quality portions of the occupants' lives.

Discussion beyond the technologies and the technical attributes, however, raised concern among many focus area participants. There was a concern that the "social" dimension of the whole house would distract from the technical research funded by the NSF Engineering directorate, and that these issues were best left to the NSF Social, Behavioral and Economic Sciences directorate. It is the position of the authors that the "whole" in whole house implicitly requires that the social dimension of the house in American culture needs to be concurrently studied with the technical dimension, currently the focus of PATH. This may require a closer integration of program goals, solicitations and reviews for award between the BES and Engineering directorates.

The discussion made clear that if a housing revolution was part of the national research agenda, the "revolutionary whole house" would need to be more broadly defined to include additional, non-traditional expectations, beyond disaster performance, durability, affordability and energy issues. The revolutionary whole house would need to positively intervene in critical social issues, from the well-being of occupants in numerous dimensions, to community well-being, to the economic and political security of society as a whole. In short, the "whole house" would become the lynchpin for the "whole town.")

If the "whole house" concept was ambiguous before the Workshop, clearly, its meaning and definition were snowballing even further during it. Upon reflection, and much negotiation, the panel realized that the synthesis of all of these concerns (both technological and social, and both historical and futurist) were what defined the "whole house." In fact, it was this synthesis that would not only unify all of the papers, but would bring about some consensus as to future work. As such, the group rallied around a final and more comprehensive order for structuring the individual papers and the entire effort. This was based on the second model (attributes and technologies), but also included potential changes that would could transform the concept of the home socially and technologically in the future. This was described in three categories:

I. Defining current attributes
The group believed that there is much to be gained by identifying, measuring, and potentially setting goals for houses and related housing research, though it was accepted that certain attributes could be measured quantitatively while others could only be qualitatively outlined.

II. Exploring technologies and processes to satisfy these attributes
Simultaneous to understanding the social needs and technical parameters of houses, the group felt that both evolutionary and revolutionary technologies that could approach those targets were called for.

III. Imagining future attributes
Finally, the group firmly supported the idea of expanding beyond our current conceptions, systems, and metrics of housing into radical revisions. This discussion, further addressed below, led to even more animated discussion among the participants, and served as the focal point for the panel.

The All-New, This "Whole House": Research Topics and Impacts

So, the group came to terms with a structure by which all of the individual projects could not only be incorporated, but could productively develop. These themes allowed the group to establish a clear vision (and subsequent agenda) for university research on the "whole house.

> **The Whole House Research Agenda is the *integration* of technologies and processes to satisfy current and anticipate future dynamic and flexible housing performance attributes, technically and socially.**

Phrased as such, a variety of different research projects were posed that refer to the original house life-cycle order, too. These include:

- ✍✍Integrative Materials
  Potential research projects that deal with this futurist vision included those looking into technologies that might be responsive, provide energy and information ("smart"), biodegradable, easily produced, capable of moving moisture, extremely durable, "self-triggering" (internal clocks for degredation), "biologically analogous," multifunctional, self-maintaining, and sustainable. In short, all of the materials would be required to integrate different performance attributes in one.

- ✍✍Integrative Methods
  Similarly, methods of design production would necessarily develop that integrate numerous technical requirements and social attributes. These include CAD/CAM and Enterprise Resource Planning (ERP) systems, modular utility systems, smart materials and reporting mechanisms for construction (information on sagging, poor construction, inspections), and self-joining materials. These production methods could even incorporate changing professionals and tradespeople by jointly articulating mutli-skilling, re-crafting, legible/transparent/self-explaining technologies (smart for all professions and occupants), and integrative design.

- ✍✍Integrative Operations
  Lastly, the group felt that additional projects could assist in social and behavioral understandings of how houses could operate that have very clear implications on technology—and could be transformed based on those technologies, as well. For example, allowing houses to perform such social tasks as house maintenance (and even housecleaning!) suggest both a centralization of functions and the need to insure that all of these functions are maintained despite the failure of one or more centralized systems. This shifting interdependence implicates both occupants and house in potentially transformative ways.

The last set of projects further spurred conceptualizations of the "whole house" that extend beyond the historical descriptions and efforts the emphasized either the technological or the social implications of physical houses. Of these, the most accepted conceptualization was the "Net-Positive Whole House"—that is, houses which contribute to their occupants, community, and environment through the integration of materials, methods, and operations. "Net-Positive" housing practices, then, would be a cluster of attributes, technologies and methods that contribute financially, environmentally, and ultimately, socially, to "net-positive" impacts.

As a preliminary conceptualization of how the group and future researchers could integrate both social and technological futures into housing, the "net-positive" house would serve as both a visual inspiration as well as a metric for future research. "Net Positive Housing Practices" is a cross-disciplinary set of projects balancing technical production systems, basic scientific discovery, focused examination of material and system interaction and the human and environment interface to produce houses that provide security from weather, geologic, biologic and criminal threats by reconceptualizing the physical, regulatory and product-delivery systems to produce housing that has a verifiable net positive effect on natural, financial, community resources or infrastructure.

The workshop participants noted that funding for science spanning across secondary systems boundaries and across directorates was an ongoing and critical need. As such, the "whole house" will not become the American house of the future without active advocacy and funding for integration of physical systems, performance, production, functional-operating and information integration practices that underpin the house as a whole. As a potential integration of both engineering, social behavorial, design, and numerous other disciplinary outlooks, “net positive house” projects could include:

1. Integration of management design, production, delivery occupant life-process support;
2. Development of advanced manufacturing information and production processes unifying quality function (user) objectives, design, modeling, simulation with manufacturing and field processes.
3. Direct development of technologies from new knowledge for accelerated broad impact.
4. Development of integrative practices for design, engineering, management and labor.
5. Development of responsive materials / coatings to collect and direct energy and water towards necessary functioning of the house and away from deteriorating and energy load increasing effects.
6. Development of new materials developed from renewable organic sources to reduce impact on the environment from the disposal and extraction functions.
7. Development of controlled or triggered biodegradable materials
8. Development of multifunctioning components to reduce overall part-counts for housing and statistically associated physical and performance defects.
9. Deploy sensing and responsive materials and networks to self diagnose and mitigate maintenance issues. (house as self - healing body)

Used as both a visual and rhetorical focus, the “net-positive” house left us with even more questions after the workshop than before, but, more importantly we were also left with both a conceptual framework for all of the projects as well as a rallying cry. Just as importantly, this conceptualization allows us to incorporate the “whole house” into the broader housing research agenda as well as demonstrate its relevance.

When considering the broad, cross-cutting impacts of this overall topic and the specific projects, moreover, we are overwhelmed with the possibilities. We have laid out clear technical areas that require both revolutionary and evolutionary change, particularly with regard to material. Such work immediately places design and construction issues squarely within the rapidly-changing fields of material science, modeling and simulation, and diagnostics. Just as importantly, if not more so, we have ventured beyond individual technical arenas into the interactions between the fields of psycho-social behavior, economics, and socio-cultural change when considering how physical transformation in the home environment can determine and be determined by changes in human conceptions of the “home.” Certainly, a “whole house” research agenda touches upon virtually every conceivable research field by its interdisciplinary essence. Such work also suggests tremendous potential technical and social change. But, if this work is so visionary and far-reaching, why haven’t we posed it before?

The Contemporary Context for the "Whole House" and Justification for Research

The unspoken reality of current "whole house" research is simply that "whole house" is not such a new concept; variations on dramatic re-conceptualization of the physical and social home have existed for at least one century. Through our discussions, though, the panel observed that previous (and many current) descriptions of the "whole house" and of "whole house" research have been incomplete. As such, a clear understanding of past and current contexts for "whole house" research was seen as an essential—and less technologically focused—research area. Indeed, definitions of housing and housing research have been socially negotiated throughout modern history. This is true for many reasons. Different consumers have different expectations and requirements of their housing, just as different homebuilders have varying capacities to deliver it. The assumption that we can design and build anything resembling an ideal home is not only culturally inaccurate but socially dangerous. Even if that were possible and our target would cease moving, new materials, technologies, and production processes would develop such that entirely new interactions would need to be considered (not to mention the fact that we would likely create new targets).

This in no way detracts from the technological work that has been and is currently being performed, nor should it result in reflexive relativism. When we look at the overarching purpose of improvements in housing technology, we usually find very worthy social and industrial goals. We also find the very methods by which we can enact technological changes that reap the benefits of "whole house" systems without wreaking the damage that previous efforts have inflicted. Rather, this analytic stance actually assists us in determining more appropriate and sensitive technological directions. It also gives us insight into our own technological motives.

What justifies the current agenda's ascendance to the national research stage? Taking the National Science Foundation's clear yet rich criteria for research merit, we can see that "whole house" conceptually and in specific project detail lay out an untapped terrain. For "Criterion 2: Broader Impacts," housing-related work are surely within the purview of national import. In fact, quality, affordable housing—and shelter of all kinds—ranks among the highest of concerns for most Americans. The potential for transformation of this highly neglected sector of the U.S. economy, society and industry through the development of integrated technical, aesthetic, environmental, and sociological research is enormous.

"Whole house" research ranks highly when considering the NSF's "Criterion 1: Intellectual Merit," as well. While numerous fields have argued how interdisciplinary efforts have lead to transformations in their knowledge base, few fields have the potential breadth of housing research. As the research area that is best positioned to synthesize and weave different disciplines together, "whole house" research poses the best opportunity to creatively develop original insight not only into the individual fields, but also into the ways that different physical and social process work in coordination. Further, "whole house" research provides the best opportunity to explore interdisciplinarity. The methods of synthesis, stochastics, and heuristics necessary for a research agenda as simultaneously material and ephemeral as housing certainly are intellectually critical.

It is no coincidence that we are having these discussions during the largest and most sustained housing boom that this country has ever witnessed, though it would not be a surprise if we would be having this same discussion during an extremely low housing production cycle. The realization that design and construction play a critical role in housing usually happens during times of crisis: homes are either too expensive to buy or to build, or a major catastrophe has struck (either natural or man-made).

What makes the current context different is the kind of groups that are interested in the "whole house." This is the first point in American homebuilding history where there are homebuilders that have enough market share to successfully invest in scaled-up, process technologies and small homebuilders that make enough profit to invest in product technologies—both with little governmental subsidy or incentive. However, they also have very little access to extensive technological resources. If, heaven forbid, the housing boom should wane, would we want to see our tremendous goals fade as well? Understanding these market segments will help researchers develop appropriate and sustainable partnerships, but also determine the technical direction of "whole house" research projects. Moreover, we can develop the arguments for investing in this work based on the beneficial goals we espouse.

Conclusion: A Whole House Agenda

So, how do we articulate a research agenda that can accommodate various interpretations of what the "whole house" should be, while still uniting these efforts into a sustainable and exciting rallying cry? Incorporating each of the technical research projects we are undertaking is a start, but examining the industrial practices and social implications that our projects would transform is as critical as our engineering plans. Linking all of these into a coalition (rather than a "system") of projects that take advantage of scale economies when needed, and flexibly accounts for when they are not, would be actual historical progress towards our "whole house."

In numerous ways, industry's view towards technological and social progress in housing mirrors the discussions held during the NSF Workshop. As represented through the PATH "whole house" roadmaps, industry clearly has been grappling with the complexity and ambiguity of such transformations:

> "The subject matter defined in… this roadmap is broad, loosely defined and largely conceptual, resting on broad mandates such as 'Change the Home Building Paradigm.' This may be appropriate or even necessary at early stages in the process, but it defers the difficult task of creating a final, operational roadmap from the first year's report. Thus, it has been challenging to balance the desire for an overarching vision and lofty goals with the practical realities of a large and diverse industry that is reluctant to change, and a small annual budget with which to bring about change." (Newport Partners 2003)

Interestingly, several research projects with much more defined objectives and realistic timetables were also imbedded within this industrial roadmap. Projects like "Apply Manufacturing Processes to Home Building," "Integrate Mechanical and Structural Systems," and "Develop Improved Job Site Assembly Techniques, Tools, and Training" suggest both an underlying appreciation for the industry's real technical and social constraints, but also an attempt to link investigations of interactions between technical systems to a broader purpose.

The research projects that have come out of both the PATH program directly and indirectly through the National Science Foundation's PATH Program Announcement as represented by the other papers in this workshop further demonstrate this tension between higher-order visions and realistic change. Yet, it has been claimed that the synthesis of social and technological transformations—and the integration of realistic increments and fundamental revolutions—demarcate the most effective strategy towards progress (RAND 2003). The NSF Housing Research Agenda Workshop's "Whole House" Panel not only endorses this view, but has herewith laid out a path towards that goal.

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