An Industrialized Solution for U.S. Urban Housing

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ABSTRACT

This paper proposes a new approach for mid-rise, multi-family urban homebuilding. The approach enhances pre-fabricated modular building systems by incorporating the open building concepts of shell/infill layering and utility disentangling. Innovative materials and components such as open-web ceiling joists, wireless electrical controls and communications, surface-mounted baseboard wiring, HVAC mini-ducts, and flexible PEX plumbing lines are critical to obtaining the advantages of open building. The result is an efficient homebuilding approach that better meets the challenges and opportunities of the future by providing tailored living environments that can more gracefully accommodate changing activities, needs, and technologies.

KEYWORDS: urban housing**,** modular housing, industrialized housing, open building, housing production

INTRODUCTION

Market studies indicate that the home buyers of tomorrow – the baby boomer and GenX population - are sophisticated, financially enabled consumers (Larson 2000) who want choice and tailored solutions in homes that:

- Closely reflect their values and needs.
- Can accommodate increasingly complex activities and work patterns.
- Can easily adapt over time as family size, financial and health conditions change.
- Can accommodate rapidly evolving technologies and services in the home.

Current homebuilding approaches do not meet these expectations. Most new homes and apartments are low-grade, low-tech, inflexible, disruptive to upgrade, high maintenance, and ill-

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designed. Few are tailored to the unique and changing needs of its occupants. Architects play no significant role in their design. The housing industry itself is decentralized, resistant to change, wary of new technology, labor intensive, inefficient, and unresponsive. It is decades behind other industries in taking advantage of new materials, technologies and processes (Larson and Mullens 2002).

This paper proposes a new approach for mid-rise, multi-family urban homebuilding, which is likely to become the dominant new housing type in the U.S. as baby boomers retire. The approach enhances pre-fabricated modular building systems by incorporating the open building concepts of shell/infill layering and disentangling. The result is an efficient homebuilding approach that better meets the challenges and opportunities of the future by providing tailored living environments that can more gracefully accommodate changing activities, needs, and technologies. The new urban homebuilding approach as well as it impact on manufacturing, construction, and remodeling processes is detailed by Mullens et al (2005).

Modular homebuilding is an increasingly popular approach to industrializing the homebuilding process. Modular homebuilders produce about 3% of the single family and low-rise multi-family homes built in the U.S. (Traynor 2002). In 2001 their 12% growth made them the fastest growing segment of the housing market. Modular homebuilders use three-dimensional sections or modules that are typically 95% finished when they leave the factory (Carlson 1991). After transport to the construction site, modules are lifted by crane and assembled on a permanent foundation. The resulting home meets conventional code and zoning requirements and is typically indistinguishable from nearby conventional site-built housing. Mullens (2004) examined the production challenges faced by modular manufacturers, identified applicable state of the art research in manufacturing systems and lean construction, and proposed future research directions to bridge the gap between current research and industry needs.

Open Building is an innovative strategy that impacts conventional home design, the supply chain and the production process. Open Building divides the total process and product of house construction into two decision levels, shell and infill (Habraken 1976, Kendall 2004). The shell is the result of design decisions specific to the site, constrained by local regulations and

conventions, geo-technical and environmental conditions. Generally, the shell includes the foundations, building structure and envelope, stairs, and main mechanical/electrical/plumbing systems. The infill is the set of design decisions and products – decoupled from the shell - needed to make a shell habitable and less difficult to alter later without disturbing the shell. This approach makes it possible for a builder to offer, in a particular shell design, a variety of interior layouts, equipment and finish choices; and it allows the builder to defer these decisions (and their costs) until the point of sale without risk. At the same time, it enables individual buyers to act on their preferences and budgets, initially and over time. Open Building also enables more efficient remodeling and retrofitting during the life of the house. The infill can be subsequently updated as homeowner needs change (e.g., aging in place or family expansion/contraction) or a new homeowner brings a new set of needs.

NEW APPROACH FOR URBAN HOMEBUILDING

This research explores the new urban homebuilding approach in the context of a multi-family, mid-rise residential project (Figures 1). The project consists of a parking garage at ground level, 9 residential levels, and a social room on the top level (Figure 1). Residential levels are constructed from a total of 126 modules, 14 modules per level. Each living unit is formed from two, three, or four modules stacked horizontally and/or vertically. Each module is 10’ 0’ high x 13’ 9” wide x 42’ l” long (584 square feet). Residential levels are configured as 44 living units including a total of 12 townhouses on levels one and two and a total of 24 single-story condos and 8 two-story condos on levels three through 9. A typical three-module, single story condo is shown in Figure 1.

The open framing system for each module is composed of four major elements: chassis, floor, exterior walls, and ceiling. Together, these elements create an environment that is highly conducive to both structural longevity and interior adaptability, two of the fundamental goals of open building. The structural steel chassis is used as the stackable backbone of each module (Figure 2).

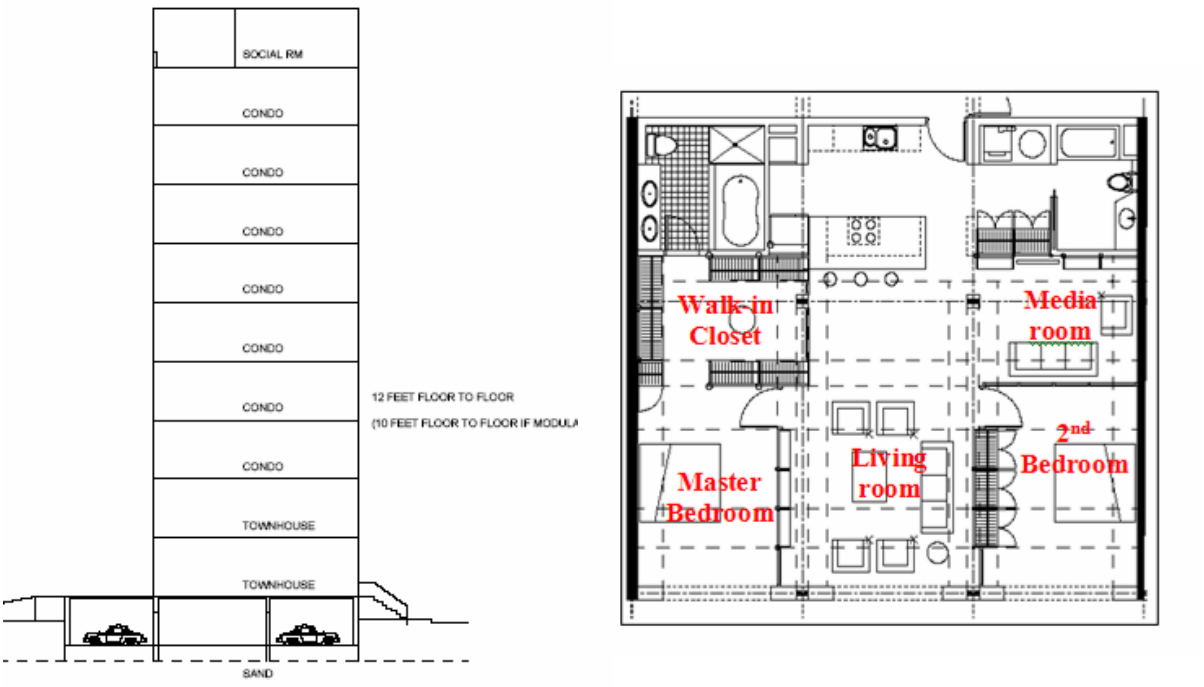

Figure 1. Multi-family mid-rise residential application: side view (left) and typical floorplan for three-module, single story condo (right) (Larson 2004)

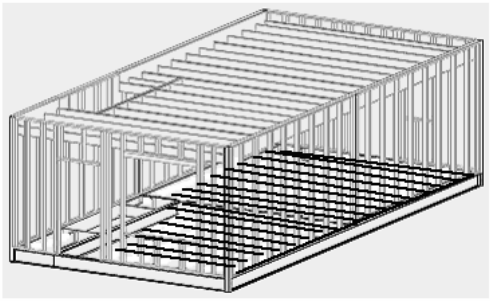

Figure 3. Typical framing of structural steel chassis (13'9" w x 42' l x 10'10" h), shown with light gauge steel exterior wall and ceiling subassemblies installed

The integrated interior infill (I^3) system consists of partitioning components such as conventionally framed interior walls, commercial open-office wall systems, and cabinet wall systems (Figure 4). I^3 components are designed to be easily installed, removed and relocated. To facilitate installation and remodeling, I^3 components are installed on top of the continuous finished floor. All I^3 components are vertically adjustable, allowing them to fit snugly against the floor and ceiling. Utility strategies described below disentangle utilities from I^3 components.

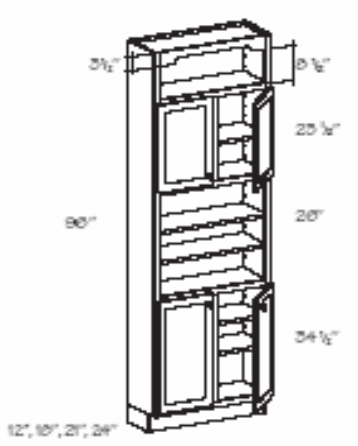

Figure 4. I^3components: commercial open office wall system from Steelcase (left) and cabinet wall system from Merrilat (right)

To facilitate utility disentangling and conserve valuable ceiling height, open-web ceiling joists are used (Figure 5). Interior climate is maintained by a forced air HVAC system utilizing natural gas fired hydronic heating and electrical powered cooling. A high velocity forced air distribution system distributes conditioned air through 4" diameter mini-ducts. The HVAC system is controlled by wireless thermostat. Electrical service is provided by a main electrical wiring run through the ceiling of each module. Wireless ceiling fixture controls and a surface mounted baseboard wiring system (Figure 6) allow further organization and disentangling of utilities. Fresh water flows through flexible PEX plumbing lines home run from manifolds in a utility closet. Telephone, data and cable signals are distributed wirelessly through wireless hubs located in a utility closet. This strategy effectively disentangles these services, both from each other and from the I^3 components.

CONCLUSIONS

This research has explored the feasibility and utility of incorporating open building concepts in modular construction in a mid-rise residential application. The approach is feasible, although changes in materials and construction processes are necessary. Innovative materials and components provide the structure necessary to apply open building concepts. Primary building components recommended include open-web ceiling joists and factory-built I^3 interior wall components. The I^3 components include movable framed interior walls, commercial open-office walls and cabinet walls. The latter two elements are part of highly engineered, vendor-supplied

wall systems. Innovative utility solutions complement the new building components, disentangling utilities from structural systems and other utilities. Utility solutions include high velocity HVAC with mini-ducts, surface-mounted baseboard wiring system, wireless controls for ceiling fixtures, flexible PEX freshwater plumbing lines, and wireless communications (telephone/cable/data). While these innovative components cost more than their conventional counterparts, they greatly reduce the effort required for construction and remodeling. In conclusion, open building concepts can be incorporated in modular homebuilding to greatly simplify both the initial production and continued remodeling of modular housing. This simplicity will come at a cost. More design effort will be required to incorporate open building concepts into each project. The innovative components that allow open building concepts to be realized are also more expensive than their conventional counterparts. Labor requirements for initial manufacturing and construction are likely to similar to conventional construction, however, future remodeling efforts are likely to be greatly reduced with the new approach.

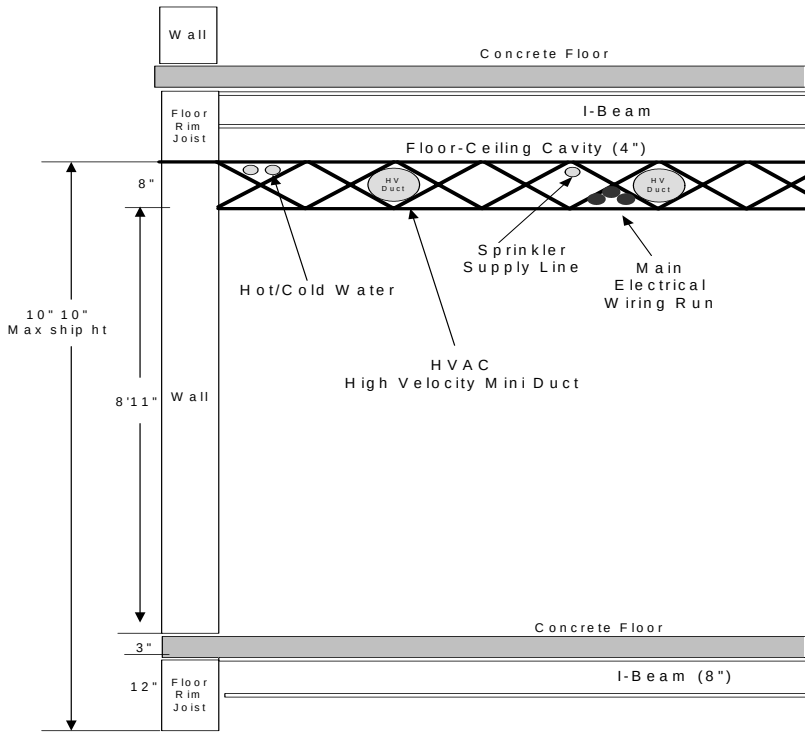

Figure 5. Typical module with open-web ceiling joists: elevation view

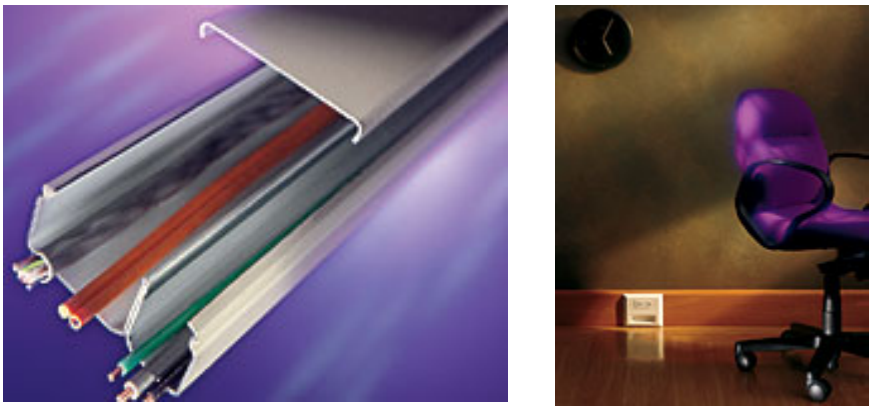

Figure 6. Surface-mounted wiring system components (left) and finished installation (right) (Wiremold)

REFERENCES

Carlson, D. (ed.) (1991). *Automated Builder: Dictionary/Encyclopedia of Industrialized Housing*, Automated Builder Magazine, Publications Division, CMN Associates, Inc., Carpinteria, CA.

Habraken, N.J., (1976). *Variations, the Systematic Design of Supports*. With J.T.Boekholt, A.P. Thyssen, P.J.M. Dinjens: MIT Laboratory for Architecture and Planning; distributed by the MIT Press, Cambridge, USA and London.

Kendall, S. (2004). An Open Building Approach to Residential Construction: A Strategy for Balancing Efficiency and Variety in Construction Management and Production. *Proceedings of the NSF Housing Research Agenda Workshop*, Feb. 12-14, 2004, Orlando, FL. Eds. Syal, M., Mullens, M., and Hastak, M. Vol 2, pg. Focus Group 1.

Larson, K. (2000). The Home of the Future. *Architecture + Urbanism: A+U,* October 2000, pg. 361.

Larson, K. (2004). *Lofts at MIT*. Drawings of proposed project. Prepared by House n, School of Architecture, MIT, Cambridge, MA, July.

Larson, K. and Mullens, M. (2002). *Collaborative Research: An Integrated Interior Infill System for Mass Customized Housing*, Proposal to NSF PATH.

Mullens, M. (2004). Production flow and shop floor control: Structuring the modular factory for custom homebuilding, *Proceedings of the NSF Housing Research Agenda Workshop*, Feb. 12-14, 2004, Orlando, FL. Eds. Syal, M., Mullens, M. and Hastak, M. Vol 2, pg. Focus Group 1.

Mullens, M., Hoekstra, R. and Nahmens, I. (2005). *An Integrated Interior Infill System for Mass Customized Housing: Final Report.* Report to National Science Foundation, prepared by UCF Housing Constructability Lab, University of Central Florida, Orlando, FL, October.

Traynor, T. (2002). Total Housing Even in 2001 at 2.219 Million, *Automated Builder*, 39(1).