Concept Home Principles -

Standardization of Measurements and Interfaces

Research Summary

June 2005

Acknowledgements

Preparation of this report was coordinated by Dr. Carlos Martín of the U.S. Department of Housing and Urban Development's Office of Policy Development and Research. The text was developed by Liza Bowles and James Lyons P.E. of Newport Partners, LLC. The assistance, support, and review by Tedd Benson of Bensonwood Homes is also acknowledged and greatly appreciated.

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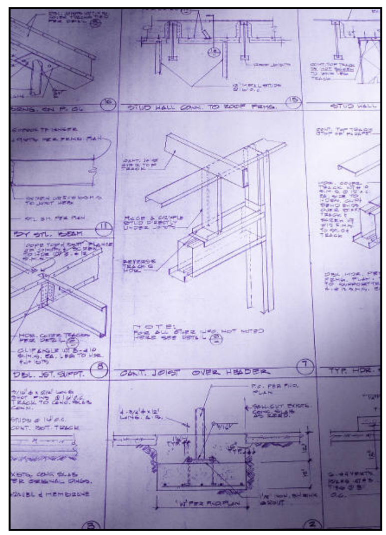
Background

Standardization of measurements and component interfaces within residential construction is a key theme in the Concept Home because it enables easier replacement of technology in houses and more rapid implementation of emerging systems. Standardization also may improve construction quality—which is often poor due in part to a low skilled, high turnover labor force—by simplifying the construction process and decreasing the necessary labor skills.

Standardization is certainly not a new concept to the home building industry. In fact, it is an essential element in an industry where thousands of separate parts and systems are manufactured, specified, installed, and inspected by a large cast of participants. Examples of standardization within the industry include:

- Lumber sizes
- Spacing of structural members
- Dimensions for plumbing and gas lines
- Electrical capacities of components
- Duct sizes
- Doorway widths
- Countertop heights
- Trim widths
- Sheathing thicknesses



Designing buildings with standardized dimensions and components can yield improved quality and production efficiencies.

Manufacturers, suppliers, designers, builders, contractors, and the building code community all rely upon these standards to integrate commonality, predictability, and efficiency into the home building process.

The focus of this Concept Home principle is to identify those areas within the home building industry where further standardization and compatibility enhancements will support homes that are easier to construct, adaptable over time, and produced in a manner that is both efficient and easier to construct, yet customized. In other words, as products and systems are developed that allow floor plans to be readily changed and homes to be produced more efficiently, what types of standardization and compatibility enhancement will be needed to transform these systems from prototypes to easily used, mainstream products? In essence, standardized measurements and interfaces is an *enabling* concept that supports several other Concept Home principles, notably flexible floor plans, organized and accessible systems, and improved production methods.

Standardization of component interfaces has long been recognized as a key to efficient production and product innovation in many industries. As an example, the standardization of computer peripheral interfaces is highlighted in this report to illustrate the benefits to the computer industry. Within the home building industry, standardization has already generated enormous efficiencies and offers the potential for further gains, but it also should be recognized that standardization does face some practical limits within the industry. For example, the variability of building sites and the non-uniform nature of local building codes can hamper many standardized solutions.

Despite this, the advancement of component and interface standardization promises benefits to manufacturers, builders, and even homeowners. Manufacturers can use standardization to guide their technology innovations so that new products will fit within the context of related building systems. In some cases, though, manufacturers may also have a disincentive to promote standardization if it commoditizes their specialty products. Builders and architects benefit from standardized interfaces by being able to design around known dimensions and specifications, while also enjoying greater product selection within a given product type (see doors example below). Lastly, homeowners stand to benefit from component interface standardization by being able to more easily replace or expand components in building systems.

Standardization within the Computer Industry – Connections for Peripherals

An interface is required when connecting peripheral devices to a PC. Traditionally, different devices used different interfaces (e.g., RS-232C or SCSI). However, this was inconvenient and sometimes led to difficulties since each device needed to be configured separately, and separate power supplies were sometimes required for each peripheral device. The data transmission speed between the PC and peripheral device is another major concern, since applications such as the Internet and downloading images require larger amounts of data to be transferred.

In 1997, interface standards USB and IEEE1394 appeared as potential solutions to these problems. The benefits of USB and IEEE1394 include: power can be supplied via the interface cable if the peripheral device is small; troublesome configuration work is reduced dramatically; and cables can be plugged in and pulled out while the PC is running. These standards have been supported since Windows 98 and are rapidly replacing others such as RS-232C.

New versions of these interfaces, called USB2.0 and IEEE1394b, have appeared recently and provide a higher transmission speed while maintaining backwards compatibility. USB2.0 is standard in almost all PCs currently on the market, and IEEE1394 is standard in high-end models. As well as connecting peripheral devices to a PC, the interfaces can be used to connect conventional peripheral devices directly to each other, such as a digital camera and printer. Use of USB is expanding to systems other than PCs, such as digital electric appliances and even automobile multi-media.

Performance Objectives

Measurement and interface standardization is an effort to achieve product and system commonality to simplify the installation and replacement of building components and building systems, and to improve compatibility with other building systems.

The Role of Standardization in Innovation

As a core principle within the Concept Home, standardization of measurements and component interfaces is examined in the context of how it can enable the innovation necessary for the Concept Home. As a prototype home design, the Concept Home will involve forward-looking technologies and systems. Such innovations may help to achieve goals like creating more adaptable floor plans, but the role of standardization in these innovations must be considered as an important factor.

Looking at an example from the computer industry can serve to illustrate the point. Standardization is clearly warranted in industries that are changing and evolving rapidly; e.g., computers and electronics. It can allow innovation to be developed and become integrated into an industry without significant disruption. A good example borrowed from the computer industry is the standardization that has occurred with the Universal Serial Bus (USB). Before USB standardization, PC peripheral connections were limited, slow, non-standardized connections, and were sometimes unidirectional. Furthermore, PC peripheral slots were limited and often unable to accommodate the proliferation of new devices coming to the market like digital cameras and personal printers. The industry sought to make new devices fully "plug and play" through the use of a standardized peripheral interface that could accommodate a vast range of products, including those yet to be developed. The USB connection has now greatly reduced configuration problems and the need for specialized connection hardware whenever a new device is connected to a PC (see side bar on previous page for more specifics.)

This serves as an excellent example of how standardization can increase the rate of adoption of new technologies. With USB standardization, cameras, printers, MP3 players, and other products have proliferated through the market. Sales are rapidly rising and proprietary connections are becoming a thing of the past. But what if there is no collective driving force for innovation within an industry? Do the same economics of standardization apply? How do we further apply standardization to home building and what are the key elements or examples? Our challenge is to delineate the technology areas or systems where standardization can help enable the adoption of the Concept Home. This paper highlights standardization approaches and technologies that can help to enable the Concept Home and key principles such as improved production processes.

Supporting Technologies and Design Approaches

Within the context of the Concept Home, standardization efforts can be considered in three major areas:

1) Standardization of design dimensions

2) Production process standardization

3) Component standardization

Standardization of Design Dimensions

Standardization of dimensions in the design phase is a powerful tool that can promote subsequent efficiencies during building construction. Standardization of dimensions employs a degree of modularity that enhances production efficiency, but it also allows for various degrees of customization by facilitating design alternatives within a structure.

> It is counterintuitive, but eventually patently obvious, that real customization (nearly infinite variation) will arise from limiting dimensions, interfaces, and positions.
>
> *- Tedd Benson, Bensonwood Homes*

One of the underlying premises of standardizing measurements is that this principle will enhance the effectiveness of CAD and CAM systems. Designing and producing homes within a context of standardized measurements will allow tools like these to evolve from design resources to systems that guide both design and production, and are used by the entire construction team including designers, engineers, and production/installation personnel. This topic is discussed further in the Improved Production Processes report.

In a design approach using standardized dimensions, a standard grid (e.g., 2'x2') is used to lay out the structure of a building. Some builders might use one increment along gable walls (e.g., 4') and another increment along eave walls (possibly a half-increment). This approach leads to a floor plan in which most rooms end up with common dimensions (e.g., 12', 14', 16'). The design of the interior floor plan will involve a much smaller grid, often in increments of 3" to accommodate standard cabinet dimensions. Combining the structure's grid with the interior grid can then result in a collection of standardized design solutions in which rooms of standard dimensions can be fitted with an interior floor plan known to work within the space.

Design standardization efforts yield more efficient production, yet they must also be viewed in the context of what building codes will allow. In some instances, design standardization efforts, such as using 2' room increments, could actually conflict with code requirements, which often have a minimum room dimension that is not on a 2' increment. Further examples of design approaches involving standardized dimensions follow.

Grid-Based Design Systems

In his book, *Building an Affordable House*, Fernando Pagés Ruiz has a useful discussion on the origin of standardization of house measurements. Pioneered by Frank Lloyd Wright, the use of a modular approach to laying out a house achieved simplicity of erection and reduced scrap and waste materials. Wright recognized that employing a set of design rules could greatly increase efficiency and effectiveness of the building process. Wright chose a 2'x4' matrix. Ruiz endorses Wright's concept of modularity and also emphasizes the affordability aspect of building in square modules versus rectangular, as rectangular modules require more linear feet of wall to achieve the same square footage as a square module.

Phase 1 of the Concept Home relied on a system modeled after the grid building system used by Tedd Benson of Bensonwood Homes. The underlying principle is that the structure of a home is designed and built on a 4' increment, with 2' increments used in some cases. This "macro" grid establishes standard dimensions for the structure and room dimensions. The interior, or “micro” grid, is laid out on a 3” grid, with 1.5” increments also used at times. The micro grid allows for a standardized design that incorporates cabinetry, and even treats wall partitions and stairs as standardized components that can be fit into the grid like any other component. By using this approach, as well as standardized solutions, for given spaces, Benson can provide homebuyers with a degree of customization and design flexibility, but does so within a non-custom, production-oriented operation.

Panel Systems

As new factory-built systems are produced for homes, design standardization plays a key role in the success of their integration into the home building process. While Structural Insulated Panels (SIPs) are certainly not new – they have been around since the 1940s – this panel system is currently gaining more attention in the industry and being produced and used more widely. SIPs consist of two outer skins and an inner core of an insulating material to form a monolithic unit. Most structural panels use either plywood or oriented strand board (OSB) for their facings. OSB is the principle facing material because it is available in large sizes (up to 12’x36’ sheets). This capacity to create large panels in a factory setting, which are then shipped to the building site, is an important production benefit of using SIPs. Structural panels can also have other materials, such as drywall, sheet metal, or finish lumber, laminated onto the OSB structural facings at the factory. This service eliminates one more step in the building process and speeds up assembly time on site.

Standard SIPs are produced in thicknesses from 4.5” to 12.25” and in sizes from 4’x8’ up to 9’x28’. Their R-values range from about R-15 for a 4.5”. EPS or XPS panel to higher than R-32 for a 6.5” urethane panel. Custom sizes and configurations are also available from some manufacturers, and virtually any bondable material can be applied as the facing material. The flexibility of the manufacturing process means that custom lengths and skins can be ordered for nearly any application.

SIP walls are often thicker than standard framed walls. For example, Insulspan™, a SIP manufacturer in Blissfield, Michigan, markets SIP walls that are 4.5" thick or 6.5" thick. As compared with traditional 2”x4” or 2”x6” exterior framing, rooms with one or more SIP exterior walls will finish out slightly larger. This carries implications for the size of the finished area in a house. A further consideration is that wider jamb extensions are needed to make the wall system compatible with standard windows and exterior doors. Thus, while the SIPs panels themselves are produced in standard thicknesses, their deviation from “normal” wall thickness dimensions must still be addressed. This example highlights that standardization efforts for a product or system may not ensure seamless compatibility with other systems.

Standardized Measurements for Modular and Whole House Systems

Standard measurements for whole-house designs rely on modules or components that individually or collectively make up the entire dwelling. Standardization at this level can provide significant onsite production efficiencies for a variety of housing applications.

One example system is ***Spacebox***, a self-contained studio residence made of high-quality composites. Units come with their own kitchen, shower, and toilet facilities, and each unit is equipped with a boiler, mechanical ventilation, and electric heating. The Spacebox unit complies with the requirements of the *Building Act of The Netherlands*.

Image Source: Spacebox (www.spacebox.info)

Residential Spacebox units all have identical unit dimensions. This allows Spacebox units to be quickly "stacked" using a light crane and put into use. The units are linked at the rear to a central walkway with a staircase on both ends. Larger buildings can be assembled using multiple units up to a maximum of three layers on a foundation of concrete plates. These qualities make the Spacebox suitable for projects involving temporary living space, but the concept could apply to permanent space as well.

The manufacturer delivers the units completely ready for use and only need to be placed on top of each other at the building site and secured. The connections for water, electricity, sewage, telephone and data transfer are advertised as easy to install. As a result, a Spacebox complex can be realized efficiently and quickly. If necessary, units can be added or removed with relative ease. Hundreds of Spacebox units are already in use and preparations are underway in several cities in Europe for placing Spacebox complexes at university campuses. While the Spacebox unit serves a different housing application than the Concept Home, it illustrates whole-house level standardization and the associated production efficiencies.

Another example of standardized measurements at the whole house level is ***FlatPak**.* The goal of the FlatPak house system is to provide a panel system that can receive different types of cladding and allow walls to be opened up easily. The FlatPak system is a flexible kit of parts. Given that there are many "kit" homes available, what makes this a better fit for the Concept Home principles? There are several interesting and relevant elements.

First, the house kit is designed to take advantage of multiple manufacturers of components rather than a single supplier or proprietary product. It uses off-the-shelf systems to ensure flexibility in product choices and a variety of combinations. It is also purported to be simple to assemble and disassemble.

Second, the frame is constructed in standardized 8' sections, which simplifies assembly and allows for sections to be substituted or changed depending on customer choices. The 8' sections can be glass, wood, concrete, or metal – or joined in various combinations using a mix and match approach.

Third, the interior space of the FlatPak house is designed on 2' standard sections to enable flexibility within a standardized context. FlatPak interior space is designed to work in a variety of configurations. Interior walls are designed to be moved, added, or subtracted as needed, without tools. One FlatPak prototype has been constructed thus far. The expectation is a total cost of approximately $140 per sq. ft., with additional design service customization at $999 per unit.

Production Process Standardization

Standardization of the building production process is a frequently cited “gap” in the home building industry, especially when it is compared with highly standardized and automated industries such as the automobile industry. While houses may be built with many standardized components, the collection of these components and the manner in which they are assembled often results in a non-standard unit that can impede efficiency of production and result in material waste.

Discussions of production process standardization often lead to the topic of factory building. Factory building may involve building entire house modules within a factory (e.g., modular and manufactured housing), constructing components like trusses or wall panels, or even bringing factory production processes on site to construction developments. Factory building can bring a strong measure of standardization to the production process, as many identical units can be manufactured on automated lines driven by software. Or – taking this concept a step further into actual business and production issues – many individual units can be manufactured on lines driven by CAD and CAM software, which enables unique components to be efficiently produced within a standardized and automated process. Two challenges of standardization within factory building are: 1) allowing *some* measure of design flexibility, and 2) integrating design, engineering, and production software such that customized component packages can be developed within a standardized production approach. These topics are explored further in the Improved Production Processes report.

Specific techniques also aid in streamlining the processes that support building production that are not necessarily directly involved in the construction itself. One fundamental, and now virtually invisible, example is the standard purchase agreements that builders have with manufacturers; the creation of a readily identified form from which one party could transfer information to another clearly involved negotiations of what should be included and excluded (i.e., standardization) and what that ultimately would look like in tangible form (i.e., a standard). A more contemporary example is the development of a common language for communicating within the digital environment, offering potential to significantly reduce transaction costs and make distinct information systems interoperable. XML (extensible markup language) standards development is one area where many of the paper-based transactions that support product ordering, invoicing, and shipping within the home building industry may be replaced by more efficient information flows. Many transactions within the vertical supply chain in home building, such as purchase orders, sales, invoices, change orders, and shipment notices, are commonly transmitted via fax or mail. When the documents are received, they are entered manually into database systems for ordering, inventory, shipping, billing, etc. This process is labor-intensive and time consuming, yet necessary, because inter-organizational information flows are limited by non-interoperable systems on each end.

XML technology offers a means for exchanging information across incompatible information systems. This technology has been widely recognized as a common medium for accurately and efficiently sharing data in the global market place. XML documents, which consist of meta-data (which describes and identifies the data) and the data itself, could automate the exchange of information found in construction business documents such as purchase orders, resulting in a more efficient production environment. In fact, the PATH program has partnered with PDX, a non-profit organization launched by the lumber industry, to develop XML standards for common business documents used in the home building supply chain (e.g., PATH and Automation of the Homebuilding Supply Chain).

Numerous other examples exist for the potential to standardize communications and decisionmaking for builders and designers. Ranging from common specifications administered by the Construction Specifications Institute (CSI) to the model building codes, these standards all assist in the final constructed homes. Such standardization is the topic of other major PATH initiatives. Just as importantly, the technologies and techniques that either enable these standards or are “wired” with them (such as IT systems) are discussed in other Concept Home principles papers.

Component Standardization

Standardizing components within home building is a means to improve product compatibility, interchangeability, and production efficiency. And while it may seem counterintuitive, standardizing building components also serves to *increase* design flexibility. For instance, consider typical interior doors with standard dimensions of 2’ 6” by 6’ 8”. Given this size standard, manufacturers are able to offer a huge spectrum of possibilities, with thousands of options ranging from less than $100 to several thousand dollars. If a door with non-standard dimensions is needed, however, the number of options is reduced to a few custom door manufacturers with limited styles and a much higher price premium.

In this example, standardizing the dimension of the door component has driven an enormous array of available products at a range of prices. Similar issues arise with the components used in residential mechanical systems like plumbing, where standardized components can lead to great flexibility for builders, contractors, and homeowners to repair, expand, and upgrade services. When systems like plumbing are comprised of standardized components and connections, the addition or replacement of components is a predictable task with many production options available. Beyond standardizing components, the use of simplified connectors and designing systems to be accessible further enhances the ability to modify services such as plumbing. This topic is discussed further in the Organized and Accessible Systems report.

Within the context of the Concept Home, standardization of components focuses on standardization needs that will support adaptable, flexible, and easily integrated building systems in a home. Since many technologies for flexible and adaptive homes are still evolving or yet to be developed, the discussions below highlight potential standardization needs that will emerge. The discussion is also highlighted with several examples of how standardization can accelerate the adoption of new components, or, conversely, how the lack of standardization may hamper implementation of new products.

In the sections below, lighting systems and SIP components are discussed as examples of innovation that have been hampered by the lack of standardization. They are very different examples in that lighting systems are products that may be challenging to replace, but SIP systems are virtually impossible to replace. In addition to these two examples, two other products/systems that could benefit from standardization, thus becoming more useful to the PATH Concept Home, are described at the end of the section.

Lighting Systems

Significant progress has been made in the area of energy-efficient lighting with the development of compact fluorescent light bulbs (CFLs) and fixtures and Light Emitting Diode (LED) lighting. However, the application and adoption of new lighting technology can be limited by compatibility issues with older fixtures, despite the apparent advantages of the new technologies.

Compatibility issues between CFLs and existing fixtures demonstrate one example. CFLs offer the advantages of lower energy consumption and longer life compared to incandescent bulbs. For example, ENERGY STAR® qualified CFL bulbs are rated to use 66 percent less energy than a standard incandescent and last up to 10 times longer. However, when integrating CFLs into existing lighting fixtures, compatibility issues like heat build-up (leading to premature failure), ability to use dimmers, ability to fit within existing fixtures, and CFL color shifts related to fixture orientation have arisen. While CFLs have experienced some success in entering the lighting market and prices have been reduced significantly since the mid-1990s, compatibility issues like these can influence consumer perceptions (even after issues have been reconciled) and hamper technology adoption.

Another example of the need to accommodate emerging technologies is LED lighting. LEDs were first developed in the 1960s as suitable for indication lighting, but have made significant progress in performance and development and can now be used for illumination. LED lighting promises to be more energy efficient and longer lasting than incandescent lighting, and researchers predict that LEDs could be available for general illumination in residential applications in five to seven years. However, designing for compatibility with the supporting light system infrastructure (i.e., electrical supply and fixtures/ballasts) is an important consideration in the integration of this technology. As LED lighting systems begin to emerge as a viable residential technology, consideration must be given to how this technology fits within the existing framework for lighting. Otherwise, the opportunity to improve lighting efficiency and performance may be compromised by compatibility issues.

SIPs Components

While standardized dimensions of SIPs panels are discussed above as an example of design standardization, the components that comprise SIPs systems provide an interesting case of *component* standardization. Along with the actual panels, SIPs manufacturers supply splines, connectors, adhesives, and fasteners to erect their systems. When engineered and assembled properly, a structure built with these panels needs no frame or skeleton to support it.

These components often are unique to a particular SIPs product and form the basis for their proprietary system. This is the method by which one manufacturer differentiates their product and is often the basis of a patent. The implication of this approach, however, is to create product differences that may negatively impact market acceptance due to increased learning curves from system to system and product compatibility issues. Beyond the initial construction of a house, non-standardized components across SIPs systems will also complicate subsequent repairs or expansions of a house. Thus, standardized components are at odds with manufacturer’s attempts to develop proprietary systems, and the overall market for SIPs could be impacted as a result.

Standardization Needs

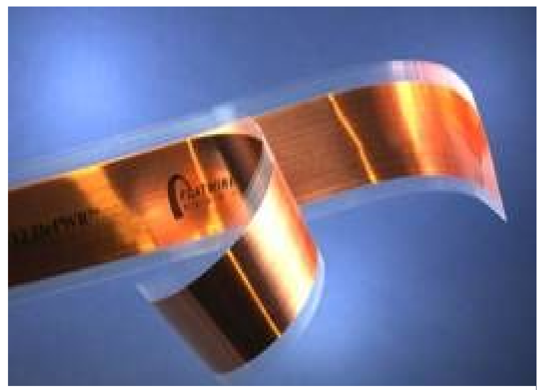
In addition to the examples above, evolving products and systems for the Concept Home will need to address integration into the existing home building context. This will require:

- Designing a product to work smoothly with existing supporting systems

- Minimizing a product's impact on other, dependent systems
- Complying with all applicable code and regulatory requirements

As an example, Decorp's flat wiring products offer an innovative technology for audio, video, data, communications, controls, and electrical wiring. While their products are at various stages of development and market-readiness, the technologies are all being designed such that they can be readily integrated into homes. Decorp's speaker wire, Audio FlatWire™, is an 8-millimeter, ultra-thin wire designed for surface application to walls, ceilings, and under floor coverings. It is currently available for purchase. Audio FlatWire™ is designed to be compatible with existing wiring systems (round wire) through the use of adapter connectors that transition the round lines to the flat wires.

This system also has a strong focus on minimizing impacts on other building systems like interior finishes. It can be run along the surface of walls and ceilings and completely concealed through the use of mesh, drywall compound, and paint or wallpaper. Decorp states that FlatWire™ currently meets Underwriters Laboratories (UL) standards, and several other Decorp products are currently in the process of gaining UL approvals.



Decorp FlatWire
Image Source: www.decorp.com

As the Concept Home designs continue to develop through the course of this project, several other products are likely to emerge as viable technologies. Depending on their stage of development, these systems will be evaluated in terms of standardization needs. Two further preliminary examples are offered below.

Interior Partitions: If the Concept Home will incorporate easily changeable floor plans that rely upon demountable, moveable interior wall systems, how will this technology be standardized such that multiple manufacturers all produce products that builders and consumers can use interchangeably? Standardization issues may include mounting systems, panel widths, panel heights, and attachment of trim products. Standardization of these system features can help transform this evolving building system from a collection of proprietary systems to a readily used and simple commodity product such as the drywall-based walls used today.

Utility Quick Disconnects: Home floor plans that are more adaptable to change must be comprised of building systems that are equally adaptable. Mechanical systems in a flexible floor plan may rely upon connections that are easy to install/uninstall without specialty tools and components or extensive knowledge of a trade. If such connections are to be adopted, standard component sizes and designs must be developed. The use of quick-connect components for air compression tools and electronics may be viewed as examples. In both of these cases, connection hardware is standardized, readily available, and allows for easy assembly and disassembly of systems.

Conclusion

Standardization of design dimensions, production processes, and components is a critical element of advancing innovation in home building. It can lead to greater design flexibility, more efficient building production, and a smother integration of innovative technologies. Given these benefits, standardization of measurements and interfaces enables several other Concept Home Principles, notably improved production processes, flexible floor plans, and organized and accessible systems. As this project advances and culminates in the development of building plans for the Concept Home, standardization will help shape the design and technologies within the Concept Home.

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