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Buildings of the Future Scoping Study: A Framework for Vision Development

February 2015

N Wang
J Goins

U.S. DEPARTMENT OF ENERGY

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

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1.0 Summary

The Buildings of the Future Scoping Study, funded by the U.S. Department of Energy (DOE) Building Technologies Office, seeks to develop a vision for what U.S. mainstream commercial and residential buildings could become in 100 years. This effort is not intended to predict the future or develop a specific building design solution. Rather, it will explore future building attributes and offer possible pathways of future development. Whether we achieve a more sustainable built environment depends not just on technologies themselves, but on how effectively we envision the future and integrate these technologies in a balanced way that generates economic, social, and environmental value. A clear, compelling vision of future buildings will attract the right strategies, inspire innovation, and motivate action. This project will create a cross-disciplinary forum of thought leaders to share their views. The collective views will be integrated into a future building vision and published in September 2015.

This report presents a research framework for the vision development effort based on a literature survey and gap analysis. This document has four objectives. First, it defines the project scope. Next, it identifies gaps in the existing visions and goals for buildings and discusses the possible reasons why some visions did not work out as hoped. Third, it proposes a framework to address those gaps in the vision development. Finally, it presents a plan for a series of panel discussions and interviews to explore a vision that mitigates problems with past building paradigms while addressing key areas that will affect buildings going forward.

2.0 Project Scope

The vision development looks across a number of performance metrics that are essential to ascertain building quality and that inform DOE's research and development work:

- energy and water consumption,
- greenhouse gas emissions and other waste,
- materials use,
- resilient design,
- occupant health and productivity, and
- cyber and physical security.

It also incorporates the infrastructure and actors that influence the way buildings are designed, built, and operated, such as:

- utility infrastructure,
- building control and communication,
- real estate market dynamics,
- construction and procurement,

- regulatory reform,[1]
- occupant needs, and
- environmental concerns.

Topics that indirectly influence the long-term trajectory of building design, such as modes of urban transportation, grid modernization, and information technology development, are also considered.

3.0 Literature Survey

The literature survey investigated past and current design paradigms and theories, their foci and outcomes. The review of building paradigms over time helped the project team understand how people suggested design, technology, and lifestyles might change while seeking solutions to their immediate problems. By understanding a past paradigm's proposals and context, and in what ways it was and was not realized, we may avoid past pitfalls while moving forward.

Tracing back to the late 19^{th} century, we investigated three distinct eras and building trends: the second industrial revolution and self-contained community planning, postwar growth and technology-oriented solutions, and energy crisis and sustainable thinking. We compared the major social, technical, and environmental challenges in each era to the prevailing design paradigms and building movement of that era. The project team then considered the following questions.

1. Did the paradigms attempt to respond to the challenges?
2. Was the approach holistic or fragmented, comprehensive or singular?
3. What were the intended effects?
4. Were those effects realized?
5. Did these effects impact the challenges?
6. What technologies or processes enabled those effects?
7. What innovations did those technologies or processes represent?

The answers to these questions revealed both positive and negative gaps between actual and intended outcomes in each era. The positive gaps reflected how buildings evolve naturally; the negative ones revealed the common pitfalls. The project team then grouped these lessons learned and used them to guide development of the current vision. The panel discussions and interviews are designed to collectively incorporate what the building community does naturally while mitigating against the community's common pitfalls.

Current building visions and commitments were reviewed as they influence the sense of what's needed. The pressing problems in buildings that need solutions now may become barriers to implementing a long-term vision if not properly addressed. A successful vision of the future should acknowledge the priorities of the era and support solutions to current problems, provide unbiased views

[1] This project assumes that the regulatory environment responds to the social, economic, and environmental conditions. This research does not imply future policy direction.

representing the common benefits of all building stakeholders, and be built on the existing knowledge and wisdom and foresee changes and evolvement in the future.

The next section discusses the gaps that were identified during the literature survey. A more detailed review will be provided in a companion report, which is planned for publication in March 2015.[1]

4.0 Gaps

Gap 1: Greater integration needed

There is no doubt that creating a sustainable built environment that supports better living is a common goal in the building community. This goal cannot be reached if design paradigms, strategies, and technical solutions are partial rather than holistic.

Past building paradigms didn't fully consider buildings as components of larger districts.[2] They either created isolated neighborhoods or zones (e.g., Neighborhood Unit [Perry 1929], Garden City [Howard 1902]) or connected buildings in a highly ordered way that did not fully respect how connectivity is naturally formed (e.g., Radiant City [Le Corbusier 1933]). In other cases, the infrastructure ended while the built environment continued (e.g., Broadacre City [Wright 1932]), breaking links and leaving gaps in between.

Current paradigms have improved in this regard. Some at least acknowledge buildings themselves as integrated technical systems. Yet, fully integrated paradigms still do not exist. A fully integrated paradigm would include occupants in the building vision while also considering the building's place in the community. It would also include an understanding of how all of these factors fit together.

Building stakeholders are working on creating this vision piece by piece and have started by identifying a number of performance metrics and corresponding quantitative goals (such as reductions in greenhouse gas emissions and energy use). However, other kinds of metrics or explicit targets have yet to be fully developed. Figure 1 groups the existing efforts by their level of development. Some areas have widely accepted metrics, well-defined targets, and identified paths forward (Group 1 in Figure 1), while others are more qualitative or anecdotal, with many unknowns (Group 3 in Figure 1). For example, it is unclear how resilience to changing environmental conditions fits into the current commitments to reduce greenhouse gas emissions. How does one align the energy efficiency goals with water efficiency and waste management? A vision of the future is intended to fit these factors together by creating a model of connectedness. Moreover, buildings must be envisioned as active components of larger districts where urban transportation, utility service, and resource exchange are equally important.

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[1] Wang N and J Goins. *Buildings of the Future Scoping Study: Learning from the Past and Current Visions*. Pacific Northwest National Laboratory, Richland, WA (Draft).
[2] *District* here does not refer to an administrative division or a particular scale. It refers to a region with a spatially or community-defined geography. It can be a planning unit at any scale.

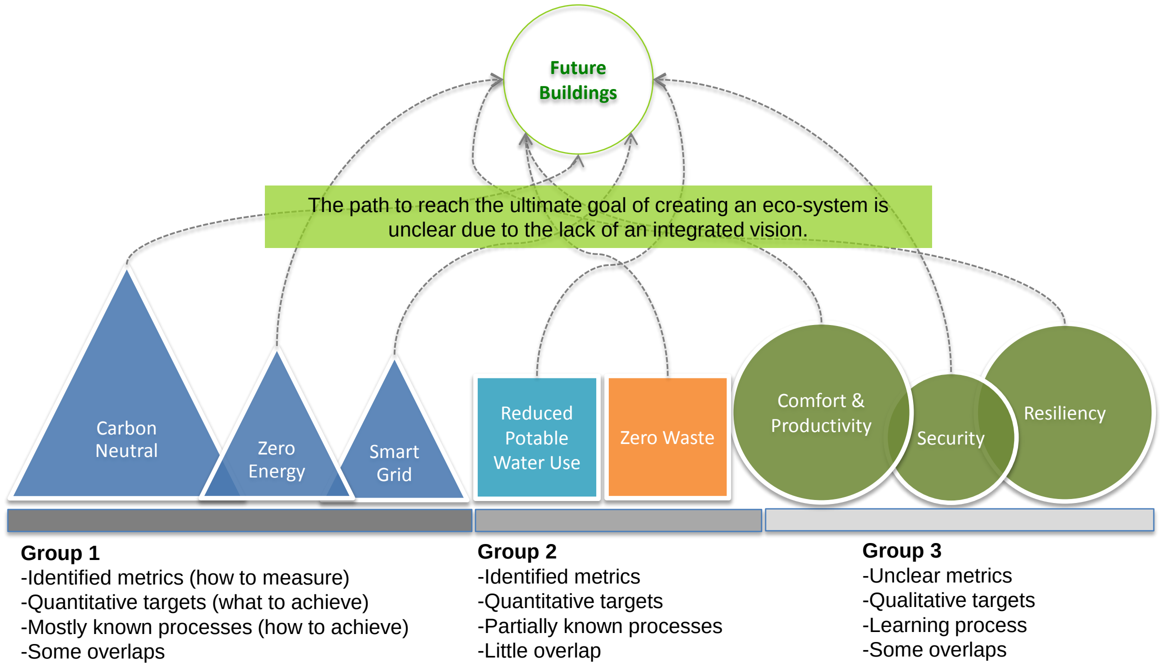

Figure 1. Building metrics grouped by their level of development.

Gap 2: Toward a proactive building design paradigm

Many building paradigms have been reactive rather than proactive. For example, building constructions were influenced by new technological processes when manufacturing successes from other industries were translated into building material production and design. Design solutions were often driven by what architects or planners saw as pressing current problems with buildings (e.g., comfort, safety, cost) and cities (e.g., crime, vandalism) or lingering problems of the past (e.g., old utility infrastructure or city facilities). Building development mostly reacted to customer needs and wants—from the automobile-based life of the suburbs to calls for near-perfect indoor environments irrespective of outdoor climatic condition and myriad household gadgets—all of which significantly drove energy demand. Less attention was given to anticipating issues that would develop into future problems (e.g., urban sprawl, climate change).

Building design has begun the shift toward a more forward-looking process. The contemporary green movement is increasingly employing environmental-responsible and resource-efficient approaches throughout a building's life-cycle. However, the early contemporary "green" buildings built in the 1990s have not reached 30 years. Thus, it remains unclear how well these buildings anticipated and will meet future needs.

A valuable vision is not intended to create solutions on a clean slate. It must respect the building evolvement process by acknowledging the known problems and current desires and foreseeing future conditions and anticipated needs.

Gap 3: Scalable solutions needed

Many visions resulted in one-off case studies rather than evolutionary and scalable solutions for mainstream buildings, due to unforeseen technical complications, cost overruns, unclear public benefits, and lack of implementation strategies.

With a more comprehensive understanding of the built environment and its impacts, the green building community has fostered many inspiring and innovative strategies and technologies. Although an analysis of 211 buildings showed that there is no significant difference in average costs for green buildings as compared to non-green buildings (Davis Langdon 2007), truly sustainable trends have not emerged in the whole building stock today. There are likely several reasons. First, buildings often have unique conditions. Case studies are difficult to compare with one another. There is no one-size-fits-all solution. Second, building stock turnover is slow. The sustainability canon is still growing, and thus there may not be enough proof yet to distinguish the long-term solutions from those with a short-term focus. It will take time to change the traditional view of green buildings as add-ons. Finally, in some cases, the building community has not agreed on how to define and measure the intangible factors. As examples, how does one quantify resilience in the building's context? Measure occupant productivity and well-being? These questions suggest how much is left to learn. Without an integrated vision to guide this learning, finding scalable solutions to improve public awareness and achieve widespread adoption remains challenging.

5.0 Propositions

This section offers propositions to fill the gaps discussed above. These propositions will be used as discussion material at the upcoming panel sessions and interviews.

Based on the lessons learned from the past visions, the project team proposes that future buildings should have the following characteristics:

- respond to and improve the many conditions that stakeholders face,
- offer coordinated, anticipatory, and participatory responses to conditions, and
- be composed of technologies and solutions that work in several contexts and in many building types.

These characteristics will add value to the buildings of the future. The project team believes that building development will be continuously driven by its "asset value." The meaning of asset value, however, will be broadened to include not only the property value, but also the recognized benefits to all stakeholders. This value proposition should not depend entirely on market transformation activities or, for example, mandating a new hedonic pricing scheme or carbon tax. Rather, future buildings will simply do more things that their stakeholders want in a more efficient, balanced way. They will offer more features that benefit the people who use them. Building assets increase in their value as they provide more benefits to their occupants, local economy, and the bigger society.

The subsequent sections add details about each bullet point above. They answer how and why these additional characteristics are valuable.

Proposition 1: Physical, financial, and social integration via robust communication

As buildings become more complex and the internet brings the world closer, building design and operation are involving more than just the traditional individual decision makers. If buildings are made of many pieces, a clearer understanding of how those pieces fit together will ensure buildings perform better. An integrated view of the links and hierarchies between the various aspects of buildings will help the building community create harmonious solutions. A fully integrated vision includes the technical, economic, societal, and environmental aspects of building design, construction, and operation. It means that various stakeholders (building owners, occupants, utility operators, financiers, etc.) will be able to communicate more effectively within and outside their groups. It also means that systems within and across buildings will be able to communicate effectively, and that buildings will be aware of their surrounding environment.

In today's model of building operation, as shown in Figure 2, one-way communication is the dominant means of controlling energy and other resource use in the built environment. For example, buildings receive control signals from their occupants through thermostats or light switches; buildings then request the needed power from the grid for normal operation. Although building control devices such as building automation systems, self-programming thermostats, automated shading devices, and daylighting controllers create a certain level of feedback loop, buildings themselves cannot make intelligent decisions based on the dynamic occupant needs, grid signals, and environmental conditions. Improved communication (i.e., multi-way and with more types of data) between occupants, interconnected buildings, and utilities is on the agenda for the future building development.

Some hold the view that more communications with occupants will be counterproductive since occupant needs increase energy use, and that occupants do not always make conscious decisions because they don't understand how building systems work. This is a one-sided view. Actual occupant needs may decrease energy use when the presumed needs are not on target (such as summer overcooling, temporarily vacant space). Dynamic, multi-way communication will enable occupants and buildings to make intelligent decisions together.

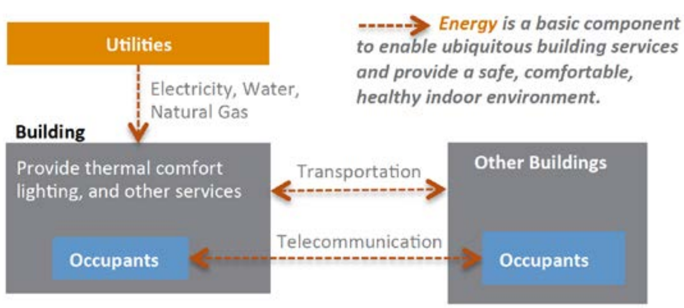

Figure 2. One-way communication, mostly driven by occupant needs, is the dominant means of controlling energy and other resource use in the built environment.

An increased level of connectedness requires infrastructure that enables it. The communication infrastructure not only includes the advanced hardware (sensors, controllers, meters, etc.) and robust control algorithms for equipment and building systems, but also a model to integrate social factors and soft benefits (such as wellbeing). A robust communications infrastructure relies on continuous communications. Understanding the hierarchies between links and their relative importance will help to ensure the communication infrastructure includes only the most useful of these while leaving out the marginally useful. Figure 3 presents a model of connectedness where energy flow is accompanied with information exchange and value recognition. The "value-added" opportunities come from understanding the human/building interface. Decisions are based on a full suite of comprehensive, transparent building performance metrics.

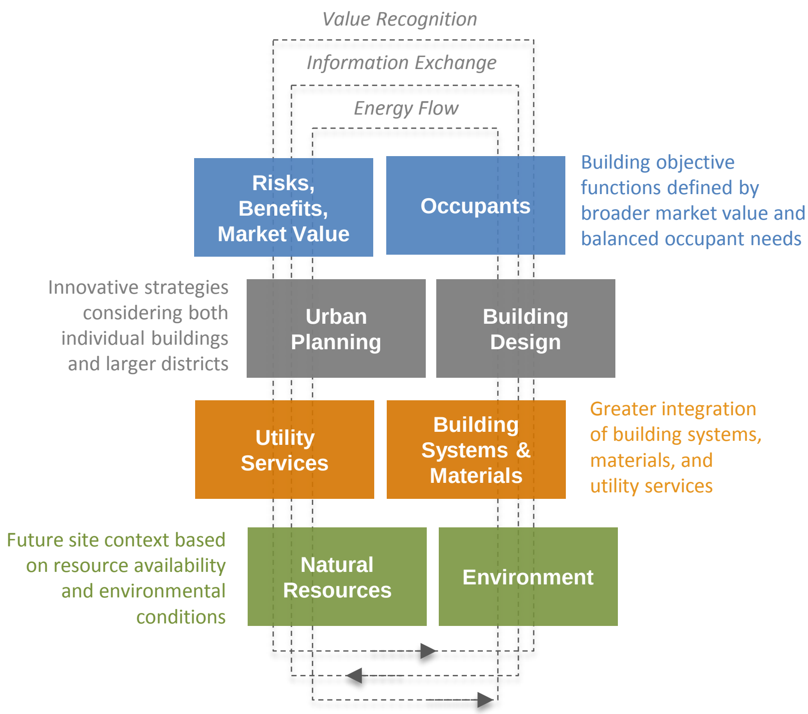

Figure 3. Dynamic, multi-dimensional resource and information exchange within and between buildings, utility infrastructure, environment, and occupants.

Proposition 2: Anticipatory and participatory buildings at district level

Buildings are shaped by the technologies, priorities, and trends of the time in which they are developed. Their service life is usually longer than that of a prevailing technology or a societal trend. On one hand, designing for longevity is an environmental imperative. On the other hand, information technology is accelerating changes in many ways that we design, build, and operate buildings, and therefore makes planning more difficult. A survey of 227 buildings (approximately half residential and half commercial) demolished between 2000 and 2003 in the city of Minneapolis/St. Paul showed that the lives of over half of these buildings were far shorter than their expected service life of at least 75 years (Connor 2004). The main reasons for their demolition were area redevelopment, lack of maintenance, and buildings becoming unsuitable for their intended use.

Buildings of the future need to anticipate the changing landscapes. These include new building typologies, ownership, building development process, etc. Telecommunication has made us start reconsidering the traditional functions of offices, schools, shopping malls, and even health care facilities. Cisco's Chief Technology Officer Padmasree Warrior predicted a future of urban transport where driverless cars will be available on demand and congestion will be a thing of the past (The Irish Times 2014). How will such a new transportation system affect urban planning? How will the rapid growing model of sharing economy (such as product service systems, redistribution market, and collaborative lifestyles [Botsman and Rogers 2010]) affect building ownership and operation? Buildings should not only anticipate and act in advance of these conditions, but also be flexible and adaptable to changing needs and technology upgrades in the future.

By and large, buildings are designed and operated to meet their own occupants' needs or other goals (such as energy efficiency or sustainability). However, an individual building has limited capability to adapt to unanticipated or unforeseen conditions. A community of buildings may provide greater capability, reduce environmental burdens, and effectively and sustainably use limited natural resources. With increased interest in and demand for resiliency and security, some in the building community turn to local strategies, such as distributed energy supply. Regardless of the future grid structure and supply chain, it is beneficial for buildings to be able to communicate and coordinate on power and other resource usage within a community.

The vision development effort will explore building and building district characteristics that will make the interactions possible and successful. These will include but are not limited to innovative storage and distribution systems, comprehensive and real-time data that can be monitored and tracked in and across buildings, and information exchange and resource trading platforms. It is also important to explore the advantages of district-level building interactions. The connected buildings can be better operated for a variety of future conditions and benefit both individual buildings and the building district as a community.

Proposition 3: Scalable technologies and processes

Technology advancements have made it possible to track where and how a building uses energy every second of the day. High-performance windows can provide high light transmission and superior thermal performance while saving energy and increasing occupant well-being and productivity. Solar panels and other clean energy sources can be integrated to make buildings energy independent. The extra power can be fed back to the power system or supplied to neighboring buildings. Buildings and the associated infrastructure can now provide environmental services to their surroundings, for example, by recycling waste water and reducing heat islands. And by using new types of materials, buildings are becoming more durable and flexible, adaptable to weather, and easily reconfigurable to fit the needs of owners and occupants.

However, the building community is far away from applying these technologies in the vast majority of buildings. In many cases, market-ready solutions only exist for new Class "A" buildings or other specialized buildings, which are a very small portion of the building stock. Older buildings, smaller buildings, and low-cost buildings, which represent the vast majority of buildings, lag behind. This fact represents research, market, and policy gaps and challenges to be addressed. Building design or retrofit decisions today have been heavily influenced by the traditional meaning of building economics, i.e., net present value, return on investment, and payback period. With energy costs remaining a small fraction of business costs in many regions, the narrow definition of costs and benefits has been a main barrier to scalable solutions. A scalable solution does not just rely on reduced first-cost or wait for energy prices to rise for a better payback. It calls for new measures of return (to people, community, and society), measures of wellbeing, and new value propositions based on complete, reliable building performance data. These data should enable a comprehensive evaluation of buildings' environmental and societal contribution, which then can be converted into a measurable market value.

This vision development effort will emphasize a norm for buildings in the future. It will look across a district, which includes many kinds of buildings. It is important to understand how the vision will fit many building types, including new building types that might evolve in the future. In this way, the proposition should be, at least, more scalable than current and past visions have been.

6.0 A Partial View

A partial view is formed based on a review of the current technology trends and visions.[1] It is intended to systematically define future building attributes as the first step of creating a new vision. A series of panel discussions and interviews will help shape this partial vision. The project team will evaluate the various perspectives and counterarguments, retain the things that work and are useful, disregard what doesn't work, and modify what's of marginal use.

A number of essential factors about building quality have been identified: energy and water use, greenhouse gas emissions and other waste, material consumption, resilient design, occupant health and productivity, and cyber and physical security. Additionally, many actors and sets of infrastructure (e.g., utility infrastructure, building control and communication, real estate market dynamics, construction and procurement, regulatory reform, occupant needs, environmental concerns, urban transportation) influence the way buildings are designed and operated. Only an integrated solution will meet the needs of the many actors involved in building design and operations while also maintaining a high level of performance on common building quality indicators. A long-term vision that integrates multiple value aspects of buildings is essential to foster the innovative solutions that will revolutionize the built environment.

Buildings of the future can have the following attributes:

1. Respond and improve the many conditions that stakeholders face via a district network.

   - Buildings can be connected to their neighbors to share, trade, buy, or sell services and resources (such as energy and water) and to keep occupants informed at an appropriate level. Buildings can also provide and trade other ecosystem services, including onsite water treatment, localized air-cleaning, or carbon capture and storage.

   - Additional actors (e.g., district system operators) have the ability to take part in distributed marketplace/sharing economy, where decision-making power is shifted to a larger group of stakeholders. Building occupants will experience increased health, productivity, and wellbeing from the enhanced indoor environmental quality and other value-added building services. The results are measurable and tracked on a real-time base.

   - This kind of coordinated action will require both utility/resource and communications infrastructures. Buildings will need advanced controls that enable management of these resources and functions. Future buildings will not rely only on the current infrastructure (electric, natural

[1] Wang N and J Goins. *Buildings of the Future Scoping Study: Learning from the Past and Current Visions*. Pacific Northwest National Laboratory, Richland, WA (Draft).

gas, and water utilities), but instead a future infrastructure can be imagined (such as partially decentralized systems for generation, distribution, storage, and/or treatment). This can take pressure off the existing centralized systems, improve system efficiency, and help buildings respond more flexibly.

2. Be anticipatory and participatory.
   - Buildings can respond to their external surroundings in near-real time to reduce energy use (e.g., using polychromic films and phase change materials). In addition to being responsive to occupants and their surroundings, buildings are goal aware, which includes a holistic set of objectives (energy use, comfort, productivity, indoor environmental quality, hedonic value, etc.). By harnessing forecasts of future weather conditions, market signals, and occupant needs, buildings can anticipate how to make better use of resources and create better conditions for stakeholders.
   - The long-term impact that a building's footprint and usage may have in the local and regional environment can be measured and tracked. This will require defining adaptable topologies for specific geographic regions, urban/rural settings, and climates. Buildings can sense and control their impact by measuring out fluxes and monitoring their contribution to the aggregate impact (i.e., urban heat island).
   - Considering the relatively long service life of buildings and the fast change in technologies and life styles, buildings are easy to reconfigure and upgrade to accommodate various needs and condition changes.
3. Utilize technologies and solutions that apply to mainstream buildings and work in a number of contexts.
   - The design and engineering of advanced building systems and components are applicable to a "norm" building, including any new building types that might develop in the future.
   - Future technologies can support easy interconnection and extensibility. This will make it possible for buildings to use smaller systems and incur lower first costs.
   - Decisions are based on the economic, environmental, and social values of the buildings and their services. These values are reflected in the buildings' holistic performance, which is measured, tracked, and recognized at all scales.

7.0 Panel Discussions and Interviews

Objectives

The propositions and partial view above will be used to promote discussion during the upcoming panel sessions with subject matter experts and interviews with thought leaders. These discussions will help participants envision the radical and breakthrough innovations required to advance to high quality built environments, rather than just mitigating against increasingly poor conditions or simply producing incremental improvements. The discussions will be treated and analyzed as interviews (of 60-90 minutes each) and will use the expertise of building subject matter experts and thought leaders.

The discussions will pose challenges in the form of future scenarios, and then inspire participants to use, develop, and modify the propositions to meet the challenges posed in the scenarios.[1] More specifically, panelists and interviewees will share their perspectives about how buildings of the future (with the characteristics mentioned above) may support or hinder desired or intended social, technical, and environmental outcomes.

The discussions and interviews will aim to:

- identify and describe the desired resource and information flows within and outside buildings (occupants, environment, utilities, other buildings);
- discuss how innovative technologies and strategies can resolve problems in buildings today and how well they might potentially work for tomorrow; and
- explore future building attributes.

Discussion Questions

Each panel or interviewee is expected to focus on one topic and discuss the following in the context of expected future conditions:

- Will building use types, functions, and ownership be the same or different? Why?
- How will societal needs (e.g., owner and occupant interests and activities) shape future buildings?
- How will climate change impact future buildings?
- How will potential changes in energy and material flow for different forms of energy, water, waste water, etc., influence buildings?
- Compared to today's practice, will there be more efficient ways of developing buildings to meet needs and adapt to changes in the future? What aspects of the built environment need to be developed, enhanced, or changed? What could drive these changes?
- What are the most important future building attributes?

Future Context

Environment and Climate Change

According to the Intergovernmental Panel on Climate Change's Fifth Assessment Report (IPCC 2014), the global surface temperature is projected to rise over the 21st century under all assessed emission scenarios, and many aspects of climate change and associated effects will continue for centuries, even if anthropogenic emissions of greenhouse gas are stopped. It is very likely that:

- heat waves will occur with a higher frequency and longer duration;
- occasional cold winter extremes will continue to occur;

[1] This approach is loosely based on the Sustainable Business Model Group's breakthrough innovation guide. See: http://www.forumforthefuture.org/sites/default/files/project/downloads/breakthrough-innovationexternal250612.pdf.

- mean precipitation will decrease in dry regions;
- sea level will rise in more than about 95% of the ocean area;
- climate change will undermine food security and reduce renewable surface water and ground water resources in most dry subtropical regions.

Population Growth

Population in the United States is projected to increase from 321 million in 2015 to 420 million in 2060 (U.S. Census Bureau 2014) and 462 million in 2100 (United Nations 2012). In 2014, 81% of the population lived in urban areas; in 2050, 87% will live in urban areas (United Nations 2014).

The above context is NOT intended to predict the future. With many possible future scenarios in mind, the purpose of setting up the future context is to pose challenges to buildings. While exploring how buildings can evolve in different ways given the above constraints, it is also essential to understand the common future building attributes regardless of the contexts in which buildings might operate in the future. The series of discussions will explore:

- the dynamic, multi-dimensional resource and information exchange within and between buildings, utility infrastructure, environment, and occupants,
- the "value-added" opportunities that come from understanding the human/building interface; and
- a full suite of comprehensive, transparent building performance metrics to describe the value proposition of future buildings.

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