The Transactive Network: Supporting New Building Paradigm

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In 2015, Pacific Northwest National Laboratory (PNNL), a U.S. Department of Energy (DOE) research facility, conducted a study for DOE on buildings of the future and developed a vision framework.

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Five key building interactions were considered, based on the roles a building should and could play in the future:

- Building and environment
- Building and utility
- The building system
- Building and occupants
- Building and community.

A list of metrics and targets was developed to inform building research, development, and design for the next century.

In order to determine the future needs of buildings, three influencing factors also were considered. One factor pertains to today's challenges and potential future challenges, such as population growth, urbanization, climate change, and energy demand. The second factor is the centric human desire for health and wellness. How can buildings support their occupants' health?

The third factor is today's rapid technology advancements. There's no way to predict what technology will look like or how it will shape society over the next century, so spaces must be designed to be flexible enough to accommodate those changes. For example, telecommunication has challenged the traditional concepts of offices and retail structures. Multi-use buildings that can adapt to future innovations will be needed. Clearly, this requires architects to think about modular, flexible designs that can be easily reconfigured to embrace advances in building technologies and materials. Understanding technology trends will help architects provide better services and inspire their creativity.

There's also a need for more integrated designs that consider buildings in time, not just space. Much of the design community still thinks of a building as a snapshot; when it's built, it's done. There may not be much thought given about what happens to the building and its occupants after 10 years, 20 years, or 50 years. Buildings that are limited by their structural and system designs can be expensive to retrofit and therefore lose their market value before their expected service life ends. This leads to resource waste in the long term. Instead, thought must be given to a building's life over time, almost as if it's a living object.

Reimagine Energy Demand and Supply

One of DOE's current research and development (R&D) investment areas exemplifies the need to design future buildings to accommodate groundbreaking technologies and methods. This effort at PNNL involves development of a transactive network between buildings and the power grid that allows buildings to actually negotiate for energy and other services. The network will help buildings become more active participants in energy distribution—like living objects, not just end-point consumers.

Currently, the interaction between a building and the grid is just one way. A building consumes energy based on its own need at any given moment. Where demand-response (DR) programs exist (allowing utilities a limited level of control over operation of building devices), the grid can signal the building and exercise DR to reduce peak demand on the energy system and maintain grid reliability. In commercial buildings, an aggregator works with building owners to temporarily reduce a building's load, which might include steps such as partially shutting down cooling systems or elevators.

The residential sector is slightly different. Homeowners sign up for an energy utility's DR program, and the utility controls home devices, such as heating, ventilation, and air conditioning (HVAC) systems or water heaters based on the grid's need. During peak times, the program shuts down the home equipment and the homeowners receive a small amount of incentives in return. The problem is, energy savings could be secondary for many homeowners. People don't want to lose control of their home's systems, especially during peak times. On a hot day, for example, everyone wants their air conditioner (AC) running. Participating in the DR program also means that homeowners need to actively "manage" conditions, such as closing the blinds on a hot day to keep the room cooler when the AC is not available. People may drop out of the program because of the inconvenience and lack of control.

The transactive network would enable two-way communication between the grid and smart devices in buildings or homes. With this network, a local control agent software understands the priority of the "connected" devices and can predict their energy use at any given moment. It can automatically place devices in reduced demand mode for a short time to provide support to the grid with minimum interruption of the home inhabitants' activities. In return, the home receives incentives and benefits of home automation.

How does this work? Every home is used by different occupants at different times. For example, if no one is home, it's likely that everything (HVAC, water heater, etc.) could be shut down for two hours. For the next-door neighbor, however, the water heater might be more important than AC, but for the homeowner across the street, the living room AC unit is more important than the one for bedrooms. Under a transactive network, home inhabitants have ultimate control. A homeowner presets preferences and priorities and decides which devices participate in transactions. The devices also learn more about preferences with time. A person can change the priorities if he/she suddenly starts working at home on Fridays and needs all devices working. Simply stated, a transactive network is value-based, with the value (cost, comfort, convenience, etc.) defined by its participants. The whole point of a transactive network is to make it effortless for the user so it becomes a natural part of daily life.

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Better Than Money

In addition to being effortless, the network has another benefit users will love. Even though it is designed for energy, it allows other services to be delivered through secured data exchange among devices. These other services might offer such futuristic features as the ability to detect problems in an AC unit and automatically alert a service provider before the unit needs a major repair or fails, or perhaps right-on-time delivery of home supplies based on laundry and dishwashing habits. There are no boundaries to the imagination.

The network will provide convenience and flexibility, making life easier and more comfortable. Ultimately, users' comfort, health, and wellness are major drivers in energy efficiency. With a new way for buildings to interact with their occupants, other buildings, the utility network, and building services, architects are empowered to create new building prototypes.

Gaps in the Market

Current home automation systems fall short of what a transactive network could do. Whole house automation is a closed system restricted by proprietary information exchange channels and with little consideration of energy consumption. Devices can't easily talk to each other—that is, a home's smart thermostat doesn't know or care what the hot water heater is doing.

With the transactive-based control and coordination network, DOE and PNNL are developing an open-system platform that allows different devices to come to the secured in-home message bus to exchange information and interact with each other. Third parties can provide their services through that same platform.

PNNL is closely working with utilities because these entities realize the aggregated value of demand reduction. They have the responsibility and the funds to develop energy efficiency and demand reduction programs. PNNL envisions that utilities will work with vendors to ensure that the products are suitable to participate in the transactive network, and also incentivize homeowners to purchase, install, and enroll their connected devices to benefit power grid operations. So utilities might work toward infrastructure as the starting point, getting all the tech-savvy or energy-savvy early adopters on board and then others will follow.

Users need to be assured of security and privacy, always important factors in developing technology. There's no existing, secure, open-source platform for the aforementioned purpose. The goal is local control, because local communication is always more secure than data leaving a home. Once benefits are demonstrated, utilities can show vendors the value of opening up their systems to enable this local communication.

Testing, 1, 2, 3, Testing

To test, PNNL is working with a few utilities across the country to gain access to sample homes. The technology (a software platform and an in-home load control agent) is installed on an off-the-shelf gateway device as a prototype solution that is suitable for installation in homes for testing. It also serves as a reference design for commercializers to create products with similar capabilities. The gateway device (the size of a laptop power adapter) plugs into the wall, connects to the home Wi-Fi, and talks to connected devices.

Right now, the focus is on big devices that have higher potential for load reduction, such as electric heating and cooling systems, water heaters, and pool pumps. Efforts haven't yet addressed washers, dryers, ovens, lighting, or other plug loads, because these smaller loads are used in shorter periods and are less predictable. It's also expected the industry will come up with various control and automation solutions once the transactive network is validated.

The testing and evaluation emphasis is on the user experience and predicted savings. Once it's shown that the installation process, user experience, and predicted savings meet the expected outcome, the next step will be expanded testing, going from a few homes to a larger number of field trials, evaluating the aggregated results. Similar work is under way on commercial buildings. The concept is the same, but with much larger devices and bigger loads. Testing of office buildings on the PNNL campus has shown promising results and gained interest from industry and utilities.

Once the fundamental R&D is enabled, others can use the new capability to provide services that lead to healthier, more productive built environments. Lighting quality, air quality, and the thermal environment can be optimized based on what matters most to occupants. All of the device data are not only collected in real time, but also exchanged in real time and fully utilized to provide more efficient and truly integrated system operation.

Transactive Network Challenges to Overcome

One challenge is working with existing building systems. Building turnover is an extremely slow process. Effective solutions are needed for what's already installed in buildings. For example, equipment performance can be very unpredictable. The manufacturer may claim certain equipment efficiency levels, but in the real world, with different maintenance, operating environments, and ambient temperatures, those performance predictions tested under standard conditions can prove unreliable. Sometimes the equipment malfunctions; sometimes it's just old. A method must be identified for working with existing equipment, and control algorithms must be developed that learn and adapt over time.

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For future buildings, the HVAC zoning and layout design pose significant challenges for adopting advanced sensing and control. Taking homes as an example, one can install temperature sensors in multiple rooms, but if the hot or cool air is delivered to these rooms at the same rate and time (because they are on the same HVAC unit without room-level automated adjustment), it is impossible to make all rooms comfortable and energy efficient. When multiple room sensors talk to a smart thermostat, the thermostat will have to choose to meet only one temperature setpoint, leaving other rooms too hot or too cold. In commercial buildings, open floor design allows flexible tenant build-out; however, the lighting or HVAC design layout may limit what can be achieved within a reasonable cost and comfort need. The future design paradigm calls for modular or flexible designs for both space and building systems, so buildings can be more easily reconfigured and retrofitted to support different functions and conditions and to adopt future technologies.

Dollars and Cents

How will the transactive network affect design and construction costs? For new constructions, it will probably require more complicated designs that can be flexible. The challenge will be retrofitting existing buildings today and in the future. Making physical changes to existing buildings, such as tightening the envelope, insulating better, and putting in energy-efficient appliances or systems will optimize the performance of the system. These all give a building the flexibility to turn on and off its mechanical and electrical equipment without greatly affecting comfort and convenience. The overall operational efficiency not only saves energy, but can help underpin building owner acceptance of the transactive network. That's more complicated than one can imagine.

At the same pace, the infrastructure of the utility system will need to change to accommodate the transactive network. The grid will need the digital setup. The system will need real-time reading and feedback, better communications, and standardized protocol. All of this is expensive, and it's not going to happen overnight.

Roll Out

Two industries that are notoriously slow to adopt new technology are building and utility, but if consumers get excited about the network, it will happen a lot faster. If they see the benefits and drive up demand for services offered on the network, capabilities will roll out more quickly. The network provides a much-needed solution for energy efficiency, but ultimately consumers need to embrace it. The design community also plays a significant role in seeding and stimulating changes in the built environment.

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