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ABSTRACT

Connected communities are groups of grid-interactive efficient buildings able to work together to address grid challenges and building needs at a community level. They provide greater benefits than building-by-building approaches, optimizing multiple buildings to reduce distribution infrastructure capacity requirements, improve grid utilization of diverse energy technologies, and create new value streams from buildings. Connected communities have been identified as an important part of decarbonizing the grid, particularly in their role to use demand flexibility to support greater degrees of variable renewable energy in the power supply.

The DOE Connected Communities program selected 10 projects throughout the U.S. to demonstrate cutting edge connected communities approaches. These projects utilize diverse energy technologies and include both residential and commercial buildings, retrofit and new construction, numbering in the tens to thousands per community. These projects are led by diverse stakeholders driven by different use cases, including utilities, homebuilders, energy service providers, universities, research organizations, and more.

To enable community-scale benefits, these projects must have control mechanisms for coordinating the operation of buildings and distributed energy resources such as generation and storage. Several types of coordinated control architectures have evolved in the Connected Communities program, influenced by the stakeholder use case, existing market conditions, and the types of building and energy resources integrated. This paper describes these architectures, as well as their use cases, benefits, and challenges they face during their implementation. The findings can support scalability of community-scale coordinated energy systems by clarifying tradeoffs in their design for utilities, control vendors, and developers.

Introduction

To reduce impacts of the climate crisis, the current administration of the United States has set ambitious goals for decarbonization, including achievement of 100% carbon pollution-free electricity by 2035 and of a net-zero emission economy by 2050 (The White House, 2024). The decarbonization of electricity production and of building energy use are critical to achieving these goals (U.S. DOS, 2021). Accordingly, grid-interactive efficient buildings, GEBs, have been investigated as a method for reducing building energy use and enabling greater penetration of variable renewable energy resources on the grid (Neukomm et al., 2019). GEBs have the potential to reduce CO2 emissions by 80 million tons by 2030 if deployed and operated correctly (Satchwell et al., 2021) . Key to this massive reduction is through the effective use of demand flexibility and distributed energy resources (DERs) such as batteries, solar PV, and electric vehicles. Demand flexibility (DF) is “the capability of DERs to adjust a building's load profile across different timescales” (Liu et al., 2022). DF may also be utilized for services including energy, reserve, frequency response, voltage management, and blackstart services (Kolln et al., 2023).

The true benefits of DF can be seen at the grid level through intelligent operation of DERs at a community level. Connected Communities (CC) are collections of buildings and DERs that coordinate multiple resources and buildings to enable increased penetration of renewable energy in the electric grid and provide grid services (Olgyay et al., 2020). A recent publication by the Rocky Mountain Institute (RMI) and the National Renewable Energy Laboratory (NREL) identified 47 projects that align to a large extent with the definition of a CC (Olgyay et al., 2020). Early demonstrations of CC include the Clean Energy and Transactive Campus, which utilized intelligent load controls and DERs as well as transactive coordination within and between buildings (Katipamula et al., 2017; Connected Communities, 2024a). Coordination of this large number of DERs improved renewable energy integration and grid reliability by delivering energy and capacity services. Another example is the Alabama Power Smart Neighborhood, in which 62 high-performance single-family homes were built with efficient and controllable appliances as well as batteries and operated in a microgrid. These batteries were operated with community solar to provide energy services as well as resiliency in case of a grid outage (DOE 2018; CC 2024b). In the case of Georgia Tech (GT) Flex, modeling and simulation was used to design and evaluate central plant and building control sequences for 18 buildings to improve efficiency and demand flexibility in response to real-time pricing (Meyer et al., 2021; CC 2024c). Each of these demonstrations are unique, while adopting some of the features that define a CC, including the use of GEBs, multiple DERs, and multi-building coordination mechanisms. These demonstrations show the significant potential of connected communities approaches, and indicate that they can be applied to different settings and use cases. However, these demonstrations were relatively small projects, with little focus on how the connected communities approach can be scaled and replicated.

To advance and better understand how to scale up these approaches, the United States DOE Connected Communities program has provided 61 million dollars in total funding to 10 Research and Development (R&D) demonstration projects (Figure 1). These demonstrations include large and small commercial, multifamily, and single-family residential, both existing and new construction, with tens to thousands of buildings per community. The projects utilize diverse sets of building and community level DERs as well as building end-uses. Each of these communities also demonstrate different sets of grid services and fulfill a different set of needs for the lead stakeholders of the projects. These stakeholders and project partners include site owners, building developers, utilities, energy service providers, universities, research organizations, and more. The scale, diversity, and complexity of these ongoing CC projects present a valuable opportunity to comprehend the cutting-edge technologies and approaches, as well as the challenges that will aid in scaling up these solutions.

To operate a connected community and provide the promised grid services, building resources and DERs must be controlled and coordinated within and between buildings. These coordination mechanisms all ultimately rely on an architecture of devices and intelligent control systems. In this paper we describe the architectures of each of the projects participating in the CC program and we synthesize them into three archetypes. Using these archetypes, we describe the factors that drive their development and usage, elucidating their use cases. Finally, we discuss a vision for their future scaling as well as the challenges and research opportunities that emerged in the CC program so far.

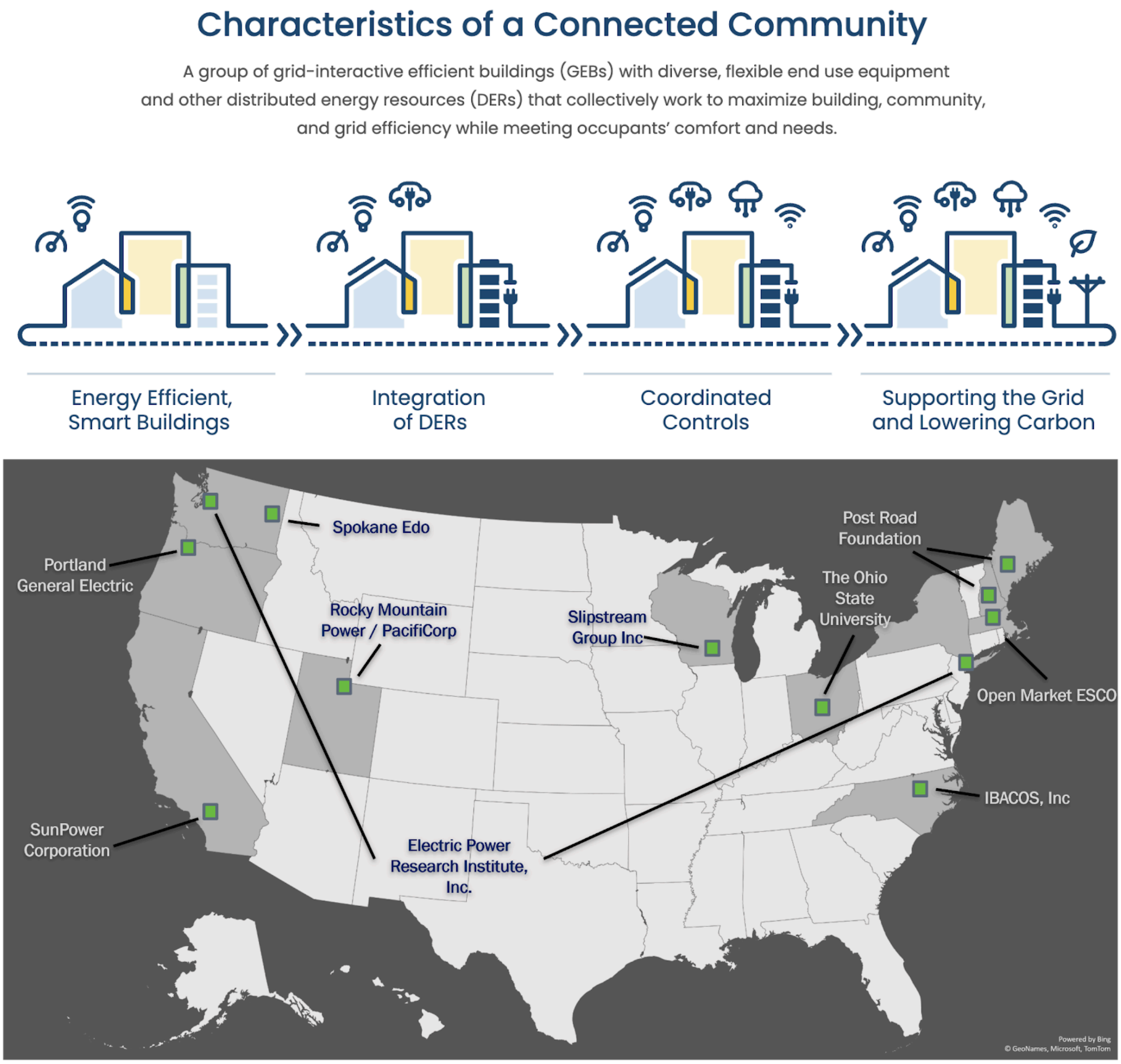

Figure 1: (top) Characteristics of a Connected Community. (bottom) Location of the ten projects. (Nemtzow et al., 2022)

Methodology

This section outlines the methodology used to achieve the objectives of this study. First, we reviewed proposal documents from each project, then we conducted interviews with key personnel in each project team. The information gathered from the interviews was synthesized, and is presented in the following results section.

We reviewed and analyzed the "technical volumes" of each project, which provided a broad understanding of the objectives of each project, the target sites and building types, the technologies used, and the composition and expertise of the project team. During the weekly cohort meetings, we gathered significant contextual details and addressed modifications in the projects from their original conception. Using this initial data, we formulated interview questions focusing on grid services, DERs, communication pathways and protocols, and control methodologies inherent in each project. We also added inquiries on hurdles encountered during the development of their coordinated control architecture or anticipated future challenges. Ten semi-structured interviews were conducted with representatives of each team in the cohort to understand different aspects of coordinated control architectures and to confirm whether any changes had occurred since the technical volume was developed. The same core set of questions were asked in each interview. Additional questions were asked where clarification or additional detail was needed. The interviews were conducted during the design or phase of each project, thus the results presented in this study reflect the plans of each project team, and are not completely defined.

A draft architecture diagram of each project team's coordinated control solution was created based on each interview. The information included in each of these system diagrams was 1) the grid entities and their basic electrical relationships; 2) the different intelligence nodes where control decisions are made; 3) the signal type (e.g. price, DR event, etc.) and protocols for communication between nodes 4) the different DERs and their interfaces (e.g. wifi-enabled thermostats, CTA-2045 water heater modules, smart inverters, etc.); and 5) the amount of sites and devices at each site. These diagrams were shared with each project team and follow-up meetings were conducted in case details of the control architecture had changed or needed to be amended. Each team also presented updated control architectures to the program cohort. These control architecture diagrams and interview results were synthesized to identify common patterns and abstracted into similar control archetypes. In addition, to facilitate comparison between the projects and understand whether projects grouped under the same archetype had specific characteristics in common, we categorized key features of each project:

1) **Lead Stakeholder Types:** Each project involves multiple stakeholders, some of which are leading the design of the project and some of which are supporting its deployment. This category shows the business segment of each of the lead stakeholders in each project, including:
    a) Utility: Electric distribution utilities or electric cooperatives.
    b) Technology Provider: Private companies demonstrating new technologies through the projects.
    c) Site Owner or Developer: Organizations owning the buildings deploying the technology or developing buildings where the technology will be deployed.
    d) Other: Unique stakeholders including research organizations, consulting groups, state agencies, etc..
2) **Grid Services:** Types of grid service involved in each project. Grid services categories include the following:
    a) Blackstart: The ability for DERs to function during a loss of system electric service and maintain operation of a site.
    b) Distribution Capacity: The ability to dynamically coordinate site loads to support distribution system assets and stressed feeders.
    c) Energy: This includes both energy and reserve services for influencing customer energy use at the wholesale level. These services are commonly referred to as load shedding and shifting.
    d) Power: This includes power quality services such as frequency response and voltage management.
3) **Building Types:** Categories of building types include the following
    a) Large Commercial: Commercial buildings larger than 50,000 sqft.

   b) Small Commercial: Commercial buildings smaller than 50,000 sqft.
   c) Multifamily: Apartment buildings containing 10+ rented units and student dormitories.
   d) Single-family: Detached single family homes
4) **DERs:** The types of DERs integrated in each project.
   a) Solar PV: Building-scale solar panels
   b) Battery energy storage: Building and community scale electrochemical battery systems
   c) EV Charging: Controlled level one and two EV charging.
   d) Water heating: Controlled HP or electric resistive water heating
   e) HVAC: Both built-up and packaged HVAC systems
   f) Other: Unique DERs including lighting, combined heat and power plants, and plug loads.

Results

Three coordinated control architecture archetypes emerged from our analysis, that we named: 1) device aggregation, 2) site optimization, and 3) distribution optimization.

In the **device aggregation archetype** (Figure 2) multiple devices at different sites are collectively coordinated to manage electricity demand in response to grid conditions.

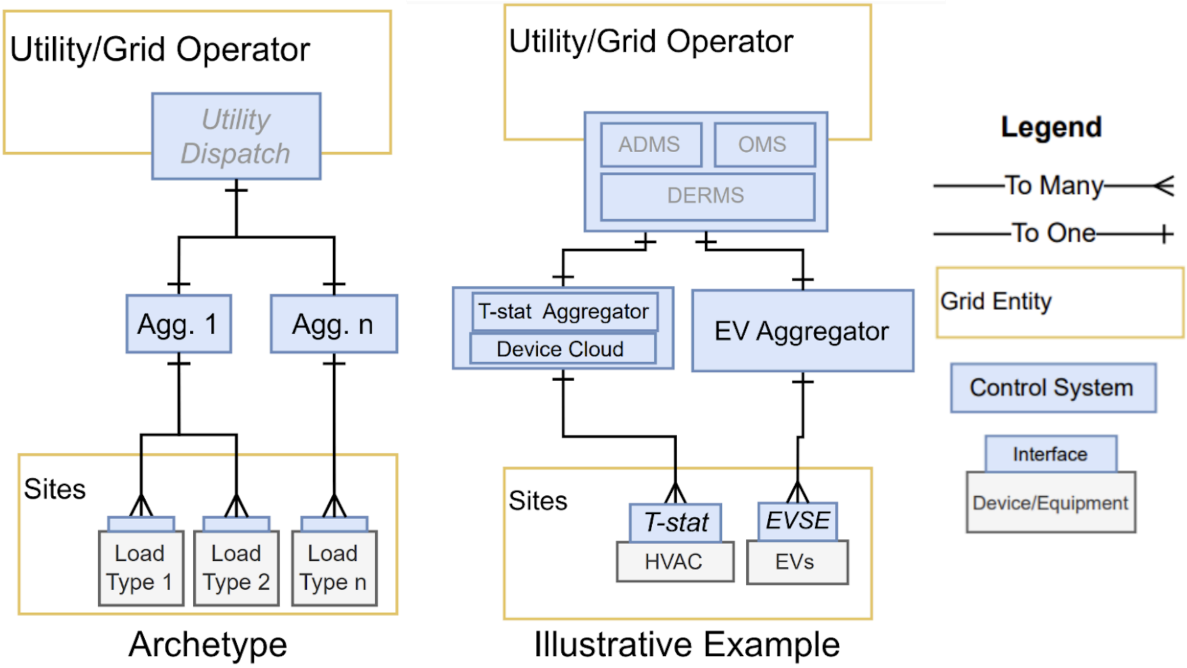

Figure 2: Device Aggregation Archetype

In this context, we define an aggregator as an entity that connects to and controls devices at customer sites, either acting on behalf of a utility or for participation in an energy market. Many currently available Bring Your Own Device (BYOD) demand response programs follow this model (ACEEE, 2019). Multiple different aggregators may be a part of this architecture, and each may manage many devices of a particular type (e.g. thermostats) at multiple different sites.

A single aggregator may also integrate with multiple different device types, but this setup is less often observed in the program, perhaps due to specialization of each aggregation provider towards a particular end-use, though they may technically integrate with many. It may also be due to commonly used pricing structures for aggregation providers. Aggregation providers running demand response programs often charge utilities and grid operators by the amount of customer devices they control. This reduces the incentive to choose a single aggregator that will integrate with every customer device, as opposed to multiple aggregators that will each integrate with some of the devices, because there may be a negligible total cost difference. Even though multiple DERs at a customer site may be integrated with aggregators, they were not observed to be coordinated with each other for holistic site-level benefit.

This architecture also generally relies on cloud computation and communication strategies to allow aggregators to control relatively simple DERs, like those found in residential buildings. Cloud communication may include multiple cloud-to-cloud pathways between the utility, aggregator, device manufacturers, each with a proprietary API integration. Some of these cloud services may play no role in controls, or may be hidden by a vendor interface and difficult to understand. For this reason they are not explicitly shown in the archetype diagram. Additionally, while aggregation platforms can be integrated with a utility dispatch system, they may also be operated independently. Each project of this type is first developing capabilities directly using the aggregation providers, with utility dispatch systems planned for the future. For this reason, the utility dispatch node is grayed out in Figure 2. An illustrative example in Figure 2 based on one of the subject CC projects is presented. In this example two aggregators are used to dispatch thermostats and electric vehicles (EV). A Distributed Energy Resource Management System (DERMS) is planned for the future, which will integrate with other existing utility systems and the aggregators to provide Virtual Power Plant (VPP) functionality, meaning that the utility can dispatch aggregated DERs and building loads to provide different energy services.

The **site optimization archetype** (Figure 3) enables optimization of Behind-the-Meter (BTM) resources at a building or group of buildings.

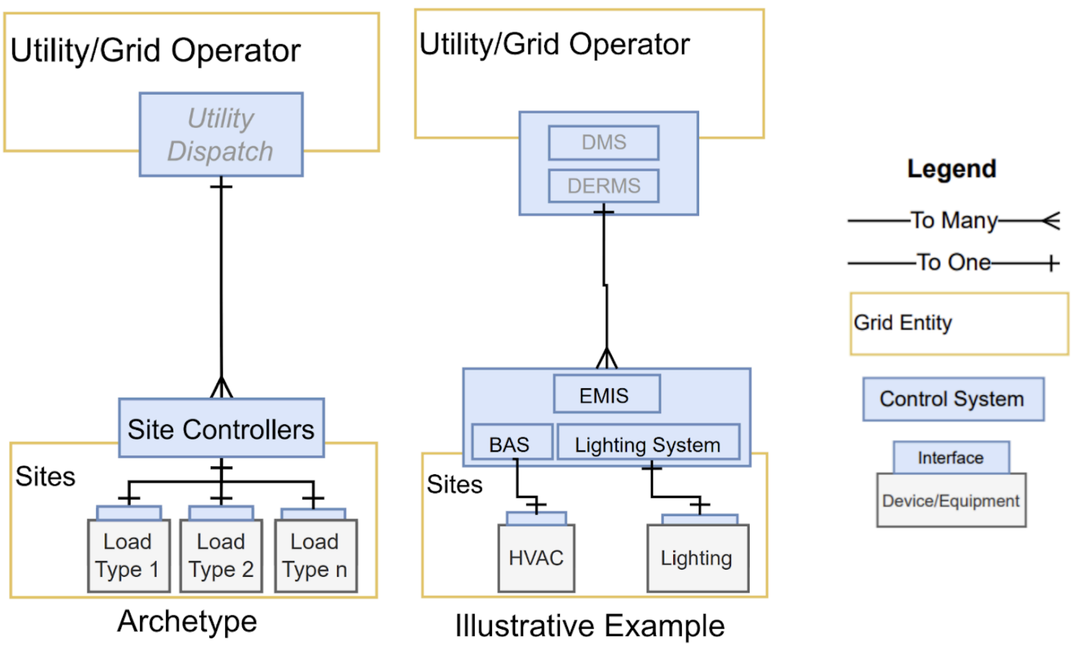

Figure 3: Site Optimization Archetype

Projects using this architecture generally have an emphasis on larger sites where intricate coordination between different systems is necessary. Large sites may be commercial buildings, apartment buildings, campuses, or other groupings of buildings like condo complexes. Customization is a critical aspect of this archetype, given the diverse and often complex nature of building systems. Each project addresses this challenge through tailored approaches to integration, involving Building Automation Systems (BAS) or DER controllers and signal integration. Typically, DERs and building resources are tackled separately, given the lack of control products that integrate both types. How DERs and building resources are integrated together differs in each project, but this shows the disconnect in systems integration approaches and commercial offerings for these cases. Some of these approaches involve some degree of custom software and control algorithm development. Additionally, traditional BAS software is narrowly focused on a subset of buildings, so there are several gaps in commercial options for GEB controls in diverse building types, particularly for multifamily buildings. Due to robust controls at the building level, utility level dispatch systems may not be required in early phases of projects adopting this architecture. Thus they are grayed out in Figure 3. The illustrative example in Figure 3, based on one of the examined CC project's control solution, shows the multiple different control systems used at the building level to integrate systems and optimize their controls. Utility dispatch is planned for the future of this project, either using a DERMS or demand response management system.

This archetype's usage is largely driven by the need for effective integration between systems within each building, which can deliver high value to building owners and occupants. This may be related to site benefits enabled by this approach, which can go beyond those offered by grid interactivity alone. Site optimization architectures synergize with known building supervisory systems such as Energy Management Information Systems (EMIS). EMIS can provide high value to buildings through functions such as fault detection and diagnostics and utility bill demand charge management (Crowe et al., 2020). Each project is leveraging standards-based communication to facilitate grid integration using protocols such as OpenADR 2.0 and IEEE 2030.5. Flexible integration with the grid will support future evolution for more diverse grid-driven use cases with more included buildings. Additionally, this architecture may enable more direct utility control of site DERs, enabling usage for grid services requiring low-latency such as frequency response.

The **distribution optimization archetype** leverages multi-level optimizations.

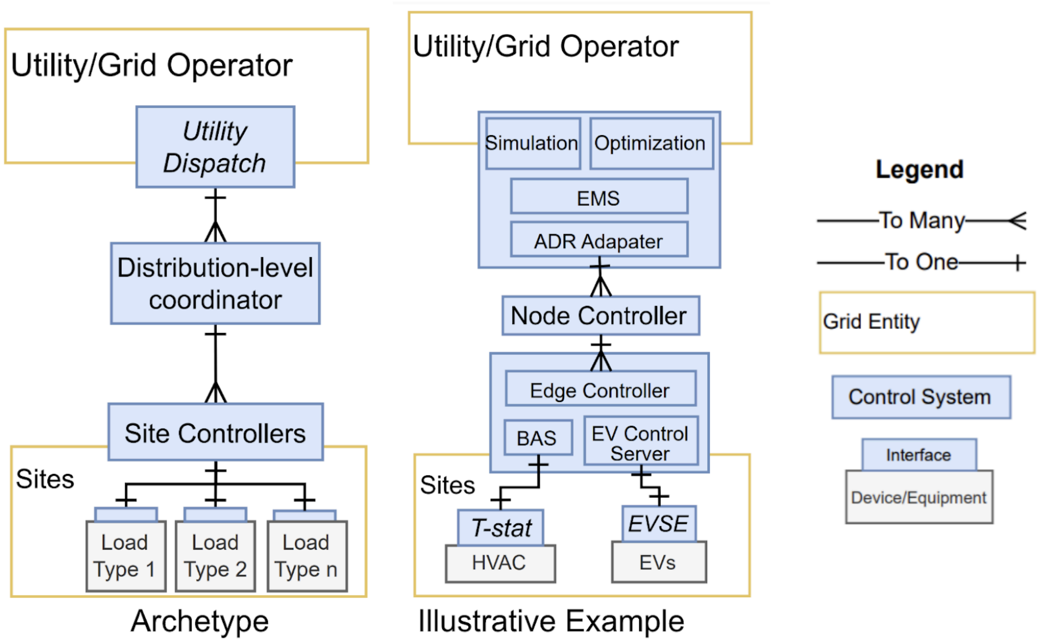

Figure 4: Distribution Optimization Archetype

This control architecture resembles a laminar control network, as defined by layered decomposition of grid coordination problems into multiple sub-problems, orchestrated by a coordinator at the top level (Ogle et al., 2021). The layered architecture increases scalability in comparison to centralized control systems, by creating decentralized interfaces to enable heterogenous integrations while limiting computational complexity. This architecture thus has the potential to reduce silos between different types of DERs, buildings, and grid management strategies that may exist in current more centralized options. However, this architecture is complex to design and may be more expensive to implement, requiring additional control elements and intelligence in comparison to the other archetypes. Principally, this archetype is effective for managing feeder loads in addition to wholesale grid services, offering a solution for precise capacity management across multiple buildings in close proximity in response to stress on distribution assets. These approaches are often referred to as non-wires alternatives to increasing capacity. The performance offered by real-time optimization assisted by distribution system awareness is one of the driving factors for this archetype's adoption.

Several required customizations underscore the innovative nature of this architecture. The projects utilizing this architecture are developing new software and control algorithms at multiple layers to achieve these optimizations. They are also developing novel business models for their solutions to emerging distribution grid challenges. Currently, coordinated control architectures of this type may have limited use cases to certain grid regions that are stressed by DERs and electrification growth, where high performance distribution optimization is worth the relatively high cost and complexity of designing these systems.

Discussion

Archetypes and project characteristics

To evaluate whether these archetypes are correlated with specific characteristics of the projects, we mapped each project to the features listed in the methodology section.

Table 1: Project Features Overview

		Site Optimization				Device Aggregation			Distribution Optimization			
	Features	P1	P2	P3	P4	P5	P6	P7	P7	P8	P9	P10
Lead Stakeholder Types	Utility	■	■			■	■				■	■
	Technology Provider							■	■	■	■	■
	Site Owner or Developer	■	■	■	■	■		■	■			
	Other		■			■		■	■	■	■	
Grid Services	Blackstart								■			
	Distribution Capacity									■	■	■
	Energy	■	■	■	■	■	■	■	■	■	■	■
	Power	■	■				■	■				■
Building Types	Large Commercial	■	■	■								
	Small Commercial						■					■
	Multifamily	■		■	■		■				■	■
	Single-Family	■				■	■	■	■	■		■
DERs	Solar PV	■	■						■			■
	Battery energy storage	■	■		■				■	■		■
	EV Charging	■	■				■		■		■	
	Water heating	■			■	■	■	■			■	■
	HVAC	■	■	■	■	■	■	■		■	■	■
	Other		■	■	■				■			

Lead stakeholders. The most common types of lead stakeholders are technology providers, utilities, and site owners or developers. Among these stakeholder types, there exists a considerable diversity of business models. Nonetheless, a discernible pattern in stakeholder engagement persists across the various types of coordinated control architecture. Device aggregation architectures are employed by currently available programs benefiting utilities through traditional DR programs as well as customers by aggregating loads into a wholesale market. They can thus be used to deliver immediate value in various paradigms, and are employed by projects involving different groups. Site optimization architectures are focused on delivering optimal control to the building, and thus are frequently led by site owner or developer stakeholders. For both site optimization and device aggregation, there is an existing body of technology developers focused on controls (e.g. EMIS, BAS, aggregation platforms), and thus these projects are focused on applying these technologies to grid use cases or buildings, with technology providers generally not leading but supporting the lead stakeholders of these projects. Though technology providers are not leading these projects, there is still some development of new control sequences, and custom integration of control systems. Additionally, R&D is focused in other areas including advancing the relationships between home owners, builders, and their utility. For distribution optimization architectures, which are cutting edge and designed to support emerging distribution system needs caused by rapidly increasing DER penetration and electrification, technology providers are highly involved. Projects using this architecture generally need to accomplish more technology and software R&D.

Grid Services. Projects include many different types of grid services and define some grid services differently. It should also be noted that every project in the program employs energy efficiency measures, underscoring its critical importance to a CC. While each coordinated control architecture enables the delivery of grid services, the distribution optimization architecture facilitates more various and deep control over energy assets in a community. This architecture may offer site optimization benefits to a building, bulk energy benefits to a wholesale market, and unique benefits to the distribution system. While this architecture may offer the greatest benefits, it is also the least mature and most costly to implement. To provide distribution benefits it also must integrate with all the various buildings in a strained region of the grid, imposing high requirements on building integration.

Types of Buildings. Projects include diverse types of buildings, both existing and new construction. For the purposes of coordinated controls, existing and new buildings are controlled in the same way. Broad categories are used for the building types. Some examples of large commercial buildings in the project include office buildings, warehouses, and university buildings. There is also diversity in the types of single family homes in the project, including both existing single family homes and master-planned communities, and multi-family homes, which include apartments and student dorms. Projects working with single family homes are generally working with a higher number of buildings than those working with multi-family and commercial to achieve a similar level of total demand flexibility. Site optimization architectures are generally being applied to large commercial buildings because of the high benefits that can be provided by coordinating and controlling diverse and more complex building systems. To a lesser extent it is being applied to multifamily buildings, however, projects have noted that good options for control systems are rare in multifamily buildings. Site optimization is more costly than device aggregation approaches that can make use of singlet devices (e.g. thermostats) at a low cost to achieve benefits over many sites with similar system configurations. For this reason, device aggregation is applied generally to single family homes that have similar systems and can be controlled with the same strategies. Distribution optimization circumvents the scarcity of site optimization control systems for non-commercial building types by developing new controls and applying them to this emerging use-case, where existing supervisory controls are poorly adapted and would not be cost effective.

Types of DER. The grid services included in each project may be delivered by a subset of DERs (e.g. frequency regulation is only offered by inverter-based resources). Though a wide range of DERs are included, every project focuses on utilizing the demand flexibility of HVAC systems. Several projects also include envelope retrofits to increase energy efficiency and further enable demand flexibility. Several unique DERs are included in individual projects, including combined heat and power systems, lighting systems, and plug loads.

Scaling Towards the Future

The coordinated control architecture archetypes—Device Aggregation, Site Optimization, and Distribution Optimization—serve distinct use cases tailored to different building types and energy management needs. Device Aggregation excels in easily scaling across many buildings with similar systems, making it particularly suitable for single-family residential buildings and small commercial structures. Its capability to integrate a substantial total load across large areas positions it well for wholesale energy use-cases. In these buildings, there are less controllable points and likely less need for a highly specific control sequence. Site Optimization, on the other hand, is designed to handle the complexities of large commercial and industrial buildings, with possible applications to multifamily structures. With the ability to integrate complex building systems and interface with higher-level systems, site optimization offers a comprehensive solution for energy management. Critically, site optimization can provide more effective service to the building and grid by applying more various and specific control schemes. Additionally, with their adoption of standards-based grid signaling protocols, it exhibits potentially easy integration with distribution optimization. Lastly, distribution optimization architectures enable expanded capabilities for control with greater ability to provide services to distribution systems. However, they must accommodate a mixture of building types and require more intricate control elements, causing relatively higher costs. To provide grid services effectively, each of these architectures seem to be focused on a different vision of scaling, representing natural directions that each architecture will evolve towards. Device aggregation architectures should spread broadly across many buildings to deliver a significant aggregate load over many low-load buildings. Site optimization should integrate many systems within a building and deploy more specific control sequences, achieving a depth of control. Distribution optimization must integrate with many such buildings, but its goal is to scale across heterogenous buildings in a small area.

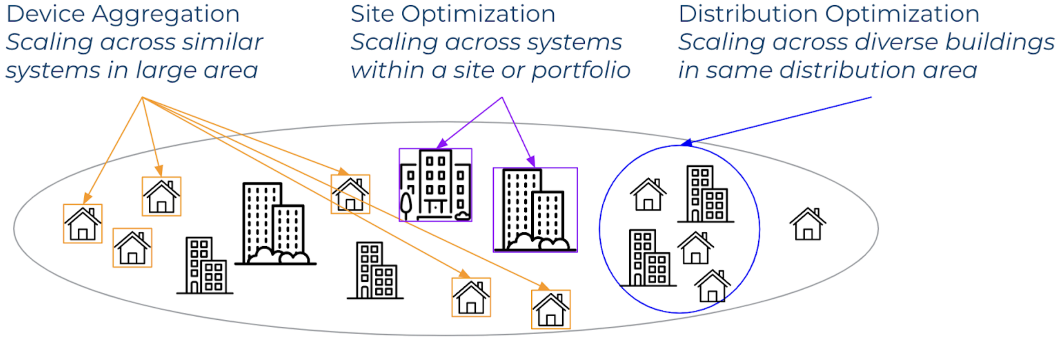

Figure 4: Archetype goals within an electric grid

There are clear benefits to each architecture, which make a strong case for their short term deployment. Future grid states with high levels of electrification and DER penetration introduce new grid challenges, including local congestion and new peaks, that make distribution optimization functions critical. However, each architecture may play a role in this future state of the grid with the introduction of a feeder level controller. While site optimization architectures can participate directly in distribution optimization schemes, device aggregation architectures may require more augmentation. All architectures will require adaptation to new data sharing and management paradigms, but device aggregation may also need additional functionality, including a geographical dispatch capability, to achieve these new more localized objectives. Achieving the different goals for each aggregator, building, and agent in the grid, while also adding the new requirements of distribution optimization introduces a difficult problem of coordination. A way to address this challenge is through a federated control architecture (Ding et al., 2022). This architecture allows for interoperability and information sharing between decentralized control systems and applications. This enables control networks for multiple grid stakeholders, potentially using different control architecture archetypes, to be coordinated together, Figure 5. This decoupling of coordination is an application of the ideas of laminar coordination (Ogle et al., 2021). Through this architecture, each of the three archetypes may evolve to support longer term grid needs, when incorporated with additional controls. Additionally, the benefits provided by relatively low cost device aggregation strategies and the deeper DF controls and other site benefits provided by site optimization (like FDD) may still be realized.

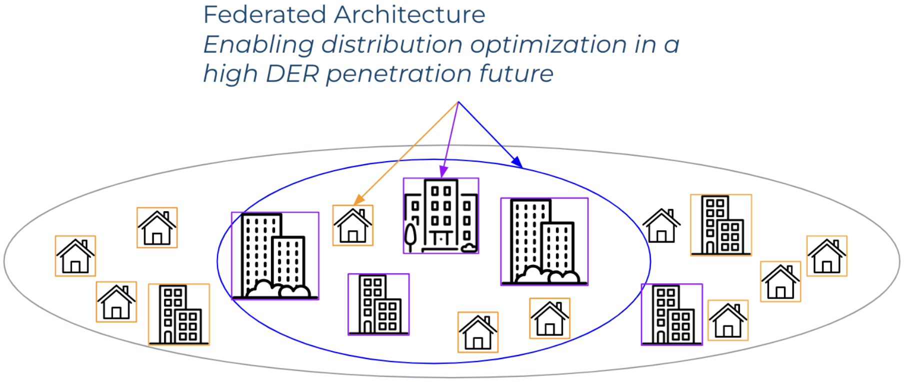

Figure 5: Future grid state incorporating federated architecture

Challenges

Technologies enabling coordinated controls have been demonstrated in various pilot projects and are emerging in industry (Olgyay et al., 2020). Though these technologies are becoming available, there are several critical short term challenges that are being observed in the CC program that should be addressed to enable CC approaches to be scalable across the country. Challenges observed in these projects include: 1) the need for interoperability between DERs, building resources, and the control systems used for coordination; 2) the difficulty in understanding and procuring the already existing coordinated control systems required by these communities; and 3) the need to develop novel business models to enable scalability for these approaches.

Interoperability has arisen as a prominent challenge for CC, as it is needed between building resources, DERs, different vendors, and the many different control systems that may exist in a connected community. Interoperability is the ability of systems to effectively communicate with each other, and it is critical to all coordinated controls. Several different areas of interoperability are defined by the GridWise Architecture Council (GWAC) and Grid Modernization Laboratory Collective GMLC, including technical, informational, and organizational (GWAC 2008; Knight et al., 2020). Technical interoperability has to do with connectivity. Despite the existence of many protocols, there are still difficulties in getting devices that can communicate. Many modern connected devices and control systems utilize cloud computing and communication enabled by API integrations, and we are seeing this model of communication frequently in each project, as it is the lowest initial cost and widely available. However, these API integrations may be costly to maintain and lead to loss of service due to changes in the APIs or in the device providers. Several efforts attempt to address these interoperability problems, including standards for modular communications like CTA-2045 (Thomas and Seal, 2017), new communication protocols like Matter (Belli et al., 2024), updates to existing standards like OpenADR (OpenADR, 2024), in addition to other standards that are emerging and in the works. However, these standards must be adopted by commercial providers to address this problem. Resolving this problem also reduces the risk of stranded assets caused by lack of connectivity, which can jeopardize a CC. In addition to standards and protocols, there must be testing procedures to ensure that connectivity is not only achievable but has the functionality and performance to support a CC use case.

Informational (semantic) interoperability refers to the ability of systems to understand and act on the information exchanged. This type of interoperability has to do with the understanding of data shared between systems, and is rare in existing systems for coordinated controls. Informational interoperability can critically reduce the cost of integration, because the meaning of data does not have to be manually interpreted. Efforts to enable semantic interoperability already exist in buildings, while several academic efforts have been proposed for the smart grid (Pritoni et al., 2020). To enable federated control and ease of integration, which will be critical in high DER and electrification scenarios, informational interoperability will be required for the additional integrations and control systems required for federated control to be feasible. New semantically interoperable data models must be developed and applied to enable these future use cases. Such data models will not only enable coordination between different grid stakeholders, but will also enable secure model exchange within large utility organizations, where shared utilization of the same DERs between transmission, distribution, generation operators is a challenge. Organizational interoperability refers to the ability for businesses to interact with aligned goals, which is deeply entwined with the business models for each stakeholder.

Several projects have encountered difficulties procuring coordinated control systems. This includes systems for building control as well as those for grid-level control, such as DERMS. For supervisory building controls, some of this difficulty can trace to the availability of control systems fit for non-commercial building types. However, project teams have had significant difficulty comparing the existing offerings of different providers to find those offering the functionality they need. Needs observed include a taxonomy with which to compare DERMS and VPP platforms, and the functionality they offer. Many connected community developers may use a Request for Proposal (RFP) process to procure this technology. A particular need is thus procurement resources such as specification guidance, which includes the technology features, capabilities, data integration, and required ongoing support of the software. Additional supporting documents may include template RFPs that enable organizations to procure project specific supervisory control technologies. Small-scale test procedures to ensure proper integration and functionality of coordinated controls may also be needed before the deployment of novel CC approaches to grid scales.

Different stakeholders may be involved in deploying CC solutions, and understanding of potential business models is critical to creating, capturing, and delivering value from demand flexibility, thus enabling these approaches to be scaled across the country. Novel CC approaches should be supported by identification of business model design options that can support CC. This should include details related to organizational interoperability such as the dependencies between stakeholders, alignment of stakeholder business models, and the financial and information streams that should exist between them. CC favor models of broad integration, data sharing, and vendor interconnection, rather than vendor lock-in. Business models for major providers will have to adapt to these features for CC approaches to flourish. The design of coordinated control architectures is deeply interlinked with stakeholder business models. Approaches to research on distribution grid architecture have demonstrated a framework for understanding the business and control domains in concert (Taft and Becker-Dippman, 2015), that should also be applied to coordinated controls.

Conclusion

CC have a pivotal role in advancing GEB technologies to provide community and grid scale benefits. Demonstrations showcased in the DOE Connected Communities program, exemplify diverse, cutting-edge approaches across the U.S. These projects are led by varied stakeholders and incorporate diverse technologies, providing an opportunity to study the various coordinated control architectures that are key to realizing these benefits. Several archetypes have evolved in these projects, including device aggregation, site optimization, and distribution optimization. These archetypes each have different benefits, use cases, and challenges. Short-term challenges include a need for interoperability, ease of comparing and procuring coordinated control systems, and development of scalable business models. Though each of these archetypes are applied to unique use cases, they each may have a role to play in the future grid state, where DER and electrification growth create new stresses on distribution grids, and demand flexibility provides opportunities for renewables integration and distribution capacity management.

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