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An Innovation Platform for the Built Environment
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Digital ecosystems in the construction industry—current state and future trends

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DIGITAL ECOSYSTEMS IN THE CONSTRUCTION INDUSTRY—CURRENT STATE AND FUTURE TRENDS

Anil Sawhney and Ibrahim S. Odeh

3.1 Aims
- Provide an overview of ecosystems and platforms.
- Provide a comprehensive review of digital ecosystems in general and in construction in particular.
- Discuss the role of the digital ecosystem in the Construction 4.0 framework.
- Articulate the purpose of the digital ecosystem in promoting innovation in the industry.
- Describe examples to explain the implementation of digital ecosystems in construction.

3.2 Introduction to digital ecosystems
A digital ecosystem is a complex intermeshing of an interdependent group of organizations, people, products, and things that work on a shared digital platform for a mutually beneficial purpose and value creation (Tiwana, Konsynski, and Bush, 2010; Gartner, 2017). Digital ecosystems have been popularized by the success of software ecosystems such as Firefox browser, Apple iOS (Tiwana, Konsynski, and Bush, 2010), and by high-tech businesses like Google, Intel, Cisco (Gawer and Cusumano, 2014), and many similar initiatives.

Digital ecosystems are the key drivers of innovation as is evident from other sectors of the economy, e.g. ride-sharing, mobile phone apps, social networking, etc. They help drive innovation both within and outside the organizations that participate in the ecosystem (Gawer and Cusumano, 2014). For example, the Apple iOS operating system is a digital ecosystem that has allowed innovation to take place in the mobile phone business by bringing organizations (Apple, app developers, hardware manufacturers, etc.), people (mobile phone users, designers, app developers, etc.), products (iPhone, iPad, iPod, etc.), and things (add-on hardware and software). Rather than selling iOS operating systems to phone manufacturers as a product, Apple has created this digital ecosystem which has driven innovation, resulting in higher profits, and value and productivity gains for users of mobile devices. There are some downsides to this phenomenon also, e.g. tight control of Apple over its devices, higher prices of iPhone, etc.
While this is a simple description of digital ecosystems, there are several other formal definitions of digital ecosystems that will be introduced in section 4 of this chapter.

### 3.2.1 Construction 4.0 and digital ecosystems

New digital and physical technologies are required to achieve the overarching vision of the Fourth Industrial Revolution (Jacobides, Sundararajan, and Van Alstyne, 2019) that underpins the Construction 4.0 (C4.0) framework. As described in the introduction chapter, the C4.0 framework relies on two broad paradigms: (1) cyber-physical systems (CPS) and (2) digital ecosystems. Innovations in both cyber-physical and digital paradigms are necessary to advance the vision of Construction 4.0 in our industry.

Figure 3.1 shows the role of digital ecosystems in the C4.0 framework. In C4.0, CPS connects the physical layer, i.e. the production space on a construction site to the digital layer. The digital layer uses the Internet of Data and Services to provide a layer consisting of a virtual model of what is being constructed and cloud-based storage to act as a repository of data and information. The top-most layer in this representation of C4.0 is the digital ecosystem that consists of a core digital platform and digital add-in tools that are known as complementary digital tools. For example, in this representation of C4.0 the construction site of building projects is the physical layer. Inside the physical layer technologies such as sensors, actuators, robotics, etc. are placed to connect this layer to the digital layer which in turn may consist of a Building Information Model (BIM) and a cloud-based Common Data Environment (CDE). Within the digital layer a BIM-based digital ecosystem exists. Organizations that are part of this BIM-based digital ecosystem work together to produce innovative solutions for various design, construction, and delivery tasks. For example, a construction company within the ecosystem can work with trade contractors and third-party software developers to develop a tool for real-time monitoring of construction workers to track the safety, productivity, and worker well-being.

At this stage, it is important to briefly discuss the broad contours of an ecosystem, especially the idea of platforms as part of ecosystems. The term ‘platform’ used in Figure 3.1 is

![Figure 3.1 Role of digital ecosystems in Construction 4.0](image-url)
crucial to the discussion about the importance of the digital ecosystem in the Construction 4.0 framework. Platforms, as will be described later, are core to the concept of ecosystems. Sometimes the terms ecosystem and platform are used interchangeably. In a digital ecosystem, software platforms that are the extensible codebase (Tiwana, Konsynski, and Bush, 2010) become the main drivers of innovation, emergent behavior of ecosystems, and creation of value. However, the idea of platforms is not new and is not specific to the software industry. In addition to digital, platforms can be business-centric platforms, product (physical) platforms, brand platforms, etc. (Sawhney, 1998).

3.2.2 Role of digital ecosystems in construction 4.0

The authors envision the co-emergence of digital ecosystems (e.g. BIM software-based ecosystems) and product ecosystems (e.g. modular or offsite product based ecosystems) in the Construction 4.0 innovation journey. This concept is illustrated in Figure 3.2. We believe that the Construction 4.0 framework is possible with a combination of three transformative processes (each illustrated as a vertical pillar in the figure):

1. Product transformation
2. Digital transformation
3. Transformation in project delivery processes and related business processes

While the digital transformation is driven by the concept of digital ecosystems, there is a need for the simultaneous evolution of product-platform based ecosystems to reap the full benefits of Construction 4.0. The transformation journey on the digital front has already begun. As an industry, we are moving away from a non-model based approach to a more model-centric approach (BorjeGhaleh and Sardroud, 2016; Sawhney, Kanzode, and Tiwari, 2017). The next step in this digital journey is the evolution towards an integrated, synchronous, and collaborative model-centric approach (World Economic Forum, 2018). Once this step is achieved the digital systems used by the industry will integrate with cyber-physical systems that, for example, will help in creating digital twins.

On the physical front, the transformation journey is also moving away from ‘stick-built’ on-site methods towards modular and offsite construction. In the physical transformation of the construction industry, product platforms can play a significant role (Bryden Wood, 2018).

As shown in the figure, the digital transformation for our industry is facilitated by digital ecosystems; the product transformation is underpinned by product platforms but is incomplete without considering changes to the current delivery and procurement regime. Therefore, concomitant with these two transformations, the industry must also transform the delivery processes and commercial terms from a transactional to enterprise-centric and integrated one (Construction Leadership Council, 2018).

For an industry that is generally regarded as a laggard when it comes to technology adoption, digital ecosystems can help it leapfrog the digital transformation and lead to sector-level productivity improvements (Cooper, 2018).

In this chapter, digital ecosystems are defined in more detail by tracking their brief history and by considering their applications in other sectors. Physical platforms and ecosystems are also briefly described as these are covered elsewhere in the handbook in chapters related to additive manufacturing and offsite construction.
Figure 3.2  Construction 4.0 transformation based on platforms and ecosystems
3.3 Current state of digital technologies in construction

The industry agenda formulated by the World Economic Forum in February 2017 summarized that ‘the construction industry has been slow to adopt new technologies and processes and over the past 50 years has undergone no fundamental change’ (Gerbert et al., 2017). This may not be for long, however. As the construction sector is seeing significant investments in new technology startups that are in the process of developing new digital tools for the industry—with some reports estimating total expenditures of $10 billion in the 18 months beginning January 2018 (Putzier, 2018), it seems that there are some changes on the horizon. However, the sector has not shown much improvement in terms of investments into information technology—68.2 per cent of companies reporting investments of 1 per cent or less as a percentage of annual sales volume in 2017 compared to 64.1 per cent of companies stating the same level of investments in 2018 (JBKnowledge, 2018).

It is now clear that the construction industry must modernize as a sector and fully embrace a digital transformation. To undertake the change, the authors feel that the traditional model of transformation popular in the industry must be documented alongside the deficiencies it generates. In Figure 3.3, we have developed a high-level illustration of the traditional model of adoption of digital technologies in construction.

Under the traditional approach, the following four challenges exist:

1. **Take-one-at-a-time approach**: most organizations consider each innovation, including digital technologies ‘one-at-a-time’ and therefore, do not gain the maximum benefits possible due to the interconnected nature of these innovative ideas (Cone, 2013). The root of this issue lies in the fragmented view of the environment-related improvements

![Figure 3.3 Traditional model of digital transformation in the construction sector](image-url)
Digital ecosystems for construction

1. Islands of automation (Hannus, 1996): with limited desire to adopt digital technologies, the construction sector has taken information technology as an isolated development of functional, departmental, or organizational solutions (Hannus, 1996; Bowden et al., 2006). This has led to a situation where ‘islands of automation’ have developed requiring a need for ‘bridges’ of interoperability. Ad-hoc development of isolated, function-driven solutions (Bowden et al., 2006) for the sector is therefore not desirable.

2. Limited integration with physical layer: the information technology implementations currently undertaken by entities in the construction sector do not consider the physical-digital-physical loop (Rutgers and Sniderman, 2018). Real-time data from the physical layer, i.e. the asset being constructed and the surrounding space is not connected back to the digital layer. This limited integration makes digital transformation in our industry difficult. Limited and ad-hoc use of sensors and edge computing leads to further fragmentation.

3. Incremental improvements in delivery processes: physical and digital transformation of the industry is usually hampered by the transactional nature of the delivery processes. The transformative initiatives in the industry do not account for the delivery processes and procurement regimes that are currently in play.

The traditional model described above leads to low uptake of digital solutions. This leads to the limited influence of the digital solutions across the life cycle stages of the projects (vertical fragmentation), across the project team members and project supply chain (horizontal fragmentation), and across ongoing and new projects (fragmentation) (Fergusson and Teicholz, 1996).

The Construction 4.0 framework in general and digital ecosystems, in particular, provide an impetus to overcome these fragmentations and therefore are crucial in the digital transformation journey.

3.4 Overview of ecosystems and platforms

To understand ecosystems and platforms, it is essential to understand the emerging shift from the traditional product-based firms where production, and to a large extent innovation, only happens inside the firm (Jacobides, Sundararajan, and Van Alstyne, 2019) to firms that use platform and ecosystem. For example, a widget-maker makes widgets (e.g. a Building Information Modeling (BIM) authoring software) and sells these widgets to the customers at a profit using the mantra of selling more and more, for less and less (as shown in Figure 3.4). Platform firms, on the other hand, use a core product (or idea or concept) and invert the firm by opening up certain portions of their product’s design to their partners and customers (Sawhney, 1998). Two sides of the market, e.g. in the case of a bidding platform shown in Figure 3.5, i.e. project sponsors and bidders come together to use the platform and extend the platform in specific (limited) ways to enhance the usage of the platform itself thus making it valuable for both sides.

Therefore, platforms are resources, computing or otherwise, that connect different stakeholder groups and derive benefits from others participating in the platform. In a platform-based approach, not only the product adds value for the respective players, but also the participation of the two sides creates additional value for these participants.
A product firm is concerned with selling a, typically standalone, product. The goal of the firm is to sell the product to as many customers as possible at the best price to maximize profits. Although the product may have to be integrated with other systems, the product firm only needs to focus on a single stakeholder group, i.e. the buyers. A platform firm, on the other hand, seeks to commercialize in a multi-sided market where, in the simplest case, suppliers and consumers transact to exchange value by using the platform. This commercialization means the platform firm needs to balance the interests of multi-sided stakeholders with their interests in a way that leads to the best value creation environment.

In Figure 3.6, this idea is extended further to introduce the concept of ecosystems. In an ecosystem, a core product, concept, or design is used as a platform to develop a business network such that entities participating in the network create additional complementary products, concepts, and designs to enhance the value for all stakeholders (Sawhney, 1998). In an ecosystem, the network effect takes over, and other firms, end-users, and a combination of firms...
and end-users start developing complementary products to serve various aspects of their business (see the example of Apple iOS in section 2). The production gets inverted—happening both inside and outside the originating firm (Jacobides, Sundararajan, and Van Alstyne, 2019). Finally, a firm organized around an ecosystem has many similarities with a platform company, especially if it owns, operates, and evolves the platform in the ecosystem. However, there are some critical differences in that functionality provided by the platform, the functionality provided by complementary products, and customer-specific functionality built by customers, are all in the same domain and center on the evolution of functionality. For instance, the platform in an ecosystem needs to continuously incorporate new features to stay valuable and avoid commoditization (Baldwin and Woodard, 2008). In this context, the firm that owns, operates, and evolves the platform needs to be very careful to ensure a balanced setting for all participants in the ecosystem governance. As shown in Figure 3.6, the bidding platform (a product) is used to not only develop bid submission functionalities but is also opened up to partners and end-users so that an ecosystem develops. Several developers use the bidding platform and extend it by developing additional complementary products, e.g. bidding analytics, bid management, bid evaluation, etc. This brings into play the network effect where users seeing more value in the ecosystem are attracted to it, thereby bringing in new users (Jacobides, Cennamo, and Gawer, 2018). Potentially the business network that surrounds the platform grows, and new constituents are added to the ecosystem, e.g. equipment and materials supply portals, sub-contractor portals, are added to the ecosystem.
In this ecosystem, the bidding platform provider opens the core platform for other firms, including customers, to develop additional customer-centric products. This development allows value creation in multiple ways and for various stakeholders. Value is created by the use of the core bidding platform and by the addition of complementary products. So project sponsors gain as more and more bidders participate. Complementors derive value by selling customer-centric products. The original firm wins more ecosystem participants as the number of players in the ecosystem increase, and as a result, more complementary products are added.

### 3.4.1 Types of ecosystems

Platforms and ecosystems are closely related terms that are used interchangeably (Altman and Tushman, 2017); there is no satisfactory resolution to the underlying lack of boundary between the two in research or practice. The critical challenge in demarcating and defining the two terms is that there are significant philosophical and practical overlaps. Based on the published literature, we feel that generally, platforms are a sub-set of ecosystems. While it is possible that platforms can exist without an explicit or clearly defined ecosystem that surrounds them in most instances, platforms form the core of an ecosystem. Generally speaking, a platform is the core ‘design, concept, idea, pattern or model’ (Baldwin and Woodard, 2008), while the business network consisting of a core organization that owns or governs the platform interacting to various degrees with external entities to generate value (Gawer and Cusumano, 2014; Altman and Tushman, 2017) is the ecosystem. We have used the taxonomy discussed by Sawhney (Sawhney, 1998); Baldwin and Woodard (Baldwin and Woodard, 2008); and Altman and Tushman (Altman and Tushman, 2017) to classify ecosystems and define both platforms and ecosystems for this handbook. Figure 3.7 shows this classification. In the literature, ecosystems can be primarily classified into:

a. Business ecosystems;
b. Innovation ecosystems; and
c. Platform-based ecosystems (also known as platform ecosystems).

There are other classifications (Gawer and Cusumano, 2014) also, but we will discuss these later in the chapter.

A business ecosystem is the network of organizations that includes suppliers, distributors, customers, government agencies, and others—involVED in the delivery of a specific product or service through both competition and cooperation (Moore, 2006).

An innovation ecosystem is based on the core organization’s use of a community of external entities, including crowd members and users to innovate (Altman and Tushman, 2017). Typically, an innovation ecosystem consists of volunteer contributors and innovation communities in which value creation happens via open innovation and open coordination (Chesbrough and Appleyard, 2007).

Platform-based ecosystems are driven by a core platform (physical or digital) upon which the ecosystem is based. Physical or product-based platforms first originated out of a need to address the high-variety challenge, i.e. the need of a firm to offer a wide variety of products in a cost-effective manner (Sawhney, 1998; Bryden Wood, 2018). Software-based or digital-platform ecosystems have an extensible software product at its core (Tiwana, Konsynski, and Bush, 2010; Um, Yoo, and Wattal, 2015). In this handbook, we focus on the platform-based ecosystems and more importantly, on digital (platform-based) ecosystems.
Some researchers have also classified ecosystems as both internal and external. Internal ecosystems are generally firm-centric that allow the firm to work by itself or with a close network of suppliers to develop a family of related products and components (Gawer and Cusumano, 2014). External ecosystems are platform based in which outside firms act as complementors (Nalebuff and Brandenburger, 1997) and provide new products and components that generate value due to network effects (Baldwin and Woodard, 2008; Gawer and Cusumano, 2014).

### 3.4.2 Digital platforms and ecosystems

A digital platform-based ecosystem consists of the following main elements:

1. **Digital platform**: the product, software, concept, idea, or thinking that a company chooses to open to others including their end-users and other firms in the hope that new products emerge and value is created manifold (Gawer and Cusumano, 2014) as compared to the value generated by a product-firm that keeps the product closed. For digital ecosystems, the platform consists of a core software product or a digital tool.

2. **Boundary objects or modules**: the artifacts that connect external complementary products to the platform to add functionality and features, some of which emerge as the ecosystem grows and adds new users. These also include interfaces that provide the specifications and design rules that describe how the platform and modules interact (Um and Yoo, 2016).

3. **Complementary products**: new products that the network of external developers develops based on the platform and by using the boundary objects available to the ecosystem participants. The complementary products add new functionality and are highly customer-centric (Tiwana, 2014). They become the key drivers of innovation.

4. **Keystone company**: this is the principal member of the ecosystem that owns, operates, governs, and evolves the platform (Iansiti and Levien, 2004). Other terms are also used to reference these companies (Gawer, 2015), e.g. keystone firms are also known as platform leaders (Gawer and Cusumano, 2002) and hubs (Dhanaraj and Parkhe, 2006).

5. **Complementors**: the developers of complementary products are called complementors. They develop complementary products to add value to the platform, the keystone company, and the end-users of the ecosystem (Nalebuff and Brandenburger, 1997; Tiwana, 2014).
The concept of digital ecosystems is illustrated graphically in Figure 3.8. A digital platform or product becomes the core component of the ecosystem. The entire ecosystem is based on the platform that provides the extensible codebase (Um and Yoo, 2016) for the core functionality of the ecosystem. Other parts of the ecosystem are the digital components, e.g. the software development kit (SDK) and the application programming interface (API) (Um, Yoo, and Wattal, 2015; Bonardi et al., 2016). Using the platform and these boundary objects (Islind et al., 2019) third-party developers, customers, and end-users come together to create and co-create add-on digital products that solve a particular problem innovatively and create value for all involved (Gawer, 2009).

For example, a BIM authoring tool can act as the core digital platform for the construction sector. The creator of the authoring tool, the keystone company, provides the boundary objects or modules that are interfaces to access the functionality of the core product. Users of the BIM authoring tool and a set of external complementors add new add-on digital products (e.g. apps) to develop new customer-centric functionality. These add-on tools or products are then made available to the broader network or ecosystem. The BIM authoring tool developer, the end-users, and the app developers all participate in this ecosystem to contribute and derive value from the ecosystem. In the platform-based ecosystem, interactions between two distinct groups (the two ‘sides’) is crucial (Tiwana, 2014). The platform’s value to a user depends on the number of adopters on the other side, i.e. growth in the number of complementors and the number of end-users must be interlinked.

### 3.4.3 Characteristics of digital ecosystems

A digital ecosystem has several characteristics that are primarily determined by the platform architecture (Tiwana, Konsynski, and Bush, 2010). The platform architecture is defined as the conceptual framework that describes how the ecosystem is divided into a
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stable core platform and a complementary set of modules or boundary objects. In addition, the architecture of the platform also consists of the rules that are binding on the platform as well as for the modules and are managed through the ecosystem’s governance mechanism. It is the platform’s architecture that positions the platform and the modules within the ecosystem. The architecture generally allows low variety and high reusability in the platform and wide variety and low reusability in the complementary modules (Baldwin and Woodard, 2008).

The challenge lies in the design of the platform architecture as this is often irreversible and must accommodate changes unforeseen at the time that the platform was created (Baldwin and Woodard, 2008). The following three distinctive perspectives can be used to define the platform architecture (Tiwana, Konsynski, and Bush, 2010):

1. Decomposition: it explains how the form and function of the digital ecosystem are broken down into subsystems (Tiwana, Konsynski, and Bush, 2010). It defines which subsystems and functionality are part of the platform codebase and which ones reside outside of it in modules and other types of boundary objects. A platform in the ecosystem is often decomposed hierarchically into smaller subsystems (Um and Yoo, 2016). Decomposition minimizes interdependence among the evolution processes of components of the ecosystem, supporting change and variation, and it also helps cope with complexity. However, it often comes with an upfront design cost and may also irreversibly constrain or overwhelmingly expand the scope and span of an ecosystem’s components.

2. Modularity: in a digital ecosystem this is crucial because it limits the impact of changes within one subsystem or module on the behavior of other parts of the ecosystem (Baldwin and Woodard, 2008; Tiwana, 2014). The modular structure of the ecosystem is a subjective choice made upfront by the keystone firm. Too few modules make the platform challenging to extend, and too many modules can leave the platform in a fragmented shape.

3. Design rules: design rules define how the ecosystem will be governed and what rules the ecosystem stakeholders will follow as the network evolves. These are set by the keystone company sometimes jointly by other players in the ecosystem. Design rules ensure interoperability with the rest of the ecosystem. Design rules must be stable and versatile (Tiwana, Konsynski, and Bush, 2010).

3.4.4 Governance of digital ecosystem

A digital ecosystem cannot be left to govern itself. Typically, the keystone firm develops implicitly or explicitly a governance structure of the digital ecosystem, where rules are set regarding the decision-making process (Tiwana, 2014). Digital ecosystem governance influences how the platform, boundary objects, complementary products and other stems of the ecosystem evolve (Gawer, 2009). The governance mechanism controls the emergent properties of the digital ecosystem. The key design feature of the governance mechanism is to strike a balance between sufficient controls over the platform to ensure the integrity of the platform while democratizing the control sufficiently to encourage innovation by the complementors. Governance of the digital ecosystem is all about sharing responsibilities and authority, governance by aligning incentives, and governance by sharing stakes (Tiwana, Konsynski, and Bush, 2010).
3.5 Digital ecosystems in construction

BIM and collaborative project management platforms are pushing the industry towards the use of digital ecosystems to address the fragmentation challenges it faces (Cooper, 2018). While the formal recognition of the idea of digital ecosystems is difficult to trace, in a recent report by the Global Industry Council, a framework based on digital ecosystems is advocated (Global Industry Council, 2018). The report suggests a digital ecosystem-based digital transformation to consolidate fragmented platforms, standardize processes, and attract digital-savvy talent.

The idea of platforms and ecosystems in the construction sector may be roughly traced to the use of procurement and bidding platforms, and materials and equipment supply portals (Noelling, 2016). These ecosystems did not address the root causes of the horizontal, vertical, and longitudinal fragmentation in the industry, but they did demonstrate the value of an ecosystem approach in the sector. Figure 3.9 illustrates the various complementary tools or applications that can be developed using the digital ecosystem concept.

More recently, major software companies with significant stakes in the construction sector have adopted the digital ecosystem approach in the hope of providing more value to their

![Figure 3.9](image-url)  
**Figure 3.9** Complementary products based on digital ecosystem
customer by bringing on board complementors especially tech startups who are willing to innovate in a customer-centric ecosystem. In the next section, we briefly provide an overview of three such construction focused digital ecosystems primarily to illustrate the concept and its benefits. Several other ecosystems are also available, but these are not covered here due to lack of space.

3.5.1 Autodesk Forge and BIM360 ecosystem

Autodesk uses the Autodesk Forge platform to promote the usage of digital ecosystems in the industry, including the construction sector. Autodesk Forge is a platform of web service APIs that allow developers to integrate Autodesk software-as-a-service (SaaS) products (such as AutoCAD, Fusion, BIM 360, etc.) into their workflows and to embed some of the components used in those products into their complementary web or mobile applications. Figure 3.10 shows the Forge ecosystem.

In early 2019, Autodesk made available the Forge Design Automation API that exposes the Revit’s engine for users and complementors to develop complementary products (see Figure 3.11). Using these APIs, users can create and modify BIM models and extract and analyze model data via an external app.

As shown in Figure 3.12, the Forge platform offers the following services externally: Authentication; Data Management; Design Automation; BIM 360; Reality Capture; Model Derivatives; Viewer; and Web-hooks.

Several external organizations have used the Forge ecosystem to develop complementary products. Autodesk provides an example of a Revit Family creation app that uses the Design Automation API of Revit for creating and editing Revit Family anytime, anywhere, without any installation of Revit software (Figure 3.13).

Autodesk Forge APIs are also available for BIM 360 Docs, BIM 360 Team, and BIM 360 Admin. Using these APIs, several complementary products are available on the Autodesk App Store.

Figure 3.10  Autodesk Forge ecosystem
(Reproduced with the kind permission of Autodesk)
3.5.2 Procore developers ecosystem

Procore’s (the platform) open Application Programming Interface (API) is another example of a construction industry digital ecosystem that has recently gained popularity. It provides the underlying framework for developing applications and custom integrations between Procore and other software tools and technologies. Customers and complementors can expand the functionality of Procore by leveraging existing integrations available in their App Marketplace (shown in Figure 3.14), or by developing new applications and customized connections using the Procore API.

The Procore API allows the ecosystem participants to leverage Procore resources within the Procore cloud using a simple architecture. The endpoints provided by Procore API are intuitive.
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and powerful, enabling the developer to easily make calls to retrieve information or execute actions on the various resources in Procore. The Procore App Marketplace serves as a repository for applications and integrations developed by the ecosystem partners using the Procore API.

These offerings allow Procore clients to integrate Procore with their existing tools and workflows. Integrations currently available in the App Marketplace expand project management possibilities for Procore clients in the areas of Analytics, Business Intelligence, Accounting, Estimating, Building Information Modeling (BIM), and others. The two primary developer personas that interact with the Procore API are Procore Clients and Procore Technology Partners.

Figure 3.13  Revit Family App using Design Automation API
(Reproduced with the kind permission of Autodesk)

Figure 3.14  Procore App Marketplace
(Reproduced with the kind permission of Procore)
3.5.3 Bentley iModel.js model server ecosystem

Bentley Systems offers an open platform for infrastructure digital twins called the iModel.js (a registered product of the company with additional information available at https://imodeljs.github.io/iModelJs-docs-output/). As shown in Figure 3.15, iModel.js is a platform that can be used by end-users and third-party developers to develop new products. For example, the platform can be used for creating, accessing, leveraging, and integrating infrastructure digital twins. The core artifacts in the platform are the iModelHub and Base Infrastructure Schema (BIS). iModelHub acts as a model server while the BIS provides a data standard for storing BIM models known as iModels. Several boundary objects are supplied as part of the platform: (a) iModel.js service; (b) iModel Sync Service; and (c) iModel Web SDK. With the help of these boundary objects, new iModels can be created from various sources of engineering data that may be stored in a Common Data Environment. The platform can be used for storing, managing, and saving changes to the iModel and other related functions.

3.6 Emerging trends and future directions—platforms and ecosystems

Digital ecosystems in construction are beneficial in several ways. In addition to driving the digital transformation that is part and parcel of the Construction 4.0, digital ecosystems can provide the following direct benefits to the industry (Global Industry Council, 2018):

1. Integration across heterogeneous internal and external systems: construction companies rely on internal and external systems and tools that are heterogeneous and fragmented. With the help of digital ecosystems organizations seamlessly combine these multiple systems and tools.
2. Rationalization and standardization: digital ecosystems can help promote rationalization of processes and practices and allow the use of standardization in data and information flow.

Figure 3.15 iModel.js Platform from Bentley Systems
3. Adoption of digital technologies: adoption of digital tools is a crucial challenge for most construction organizations due to the reluctance to change. Digital ecosystems can help overcome this reluctance by developing add-ons and additional complementary products that provide interfaces and artifacts that are more acceptable to project participants.

4. Establishing a convincing value proposition: digital ecosystems help showcase benefits of the digital transformation, making a strong value proposition to key decision-makers and stakeholders in construction organizations.

Broadly these benefits stem from the following three scenarios:

1. Software out-of-the-box does not work in construction: a significant irritant in the adoption saga of digital tools in the construction sector has been the mindset that off-the-shelf software does not work for the highly specialized processes and practices prevalent in the industry. Given that these processes and practices are generally not standardized in the companies that want to adopt digital tools, this may seem like a convincing blocker of technology. With digital ecosystems based transformation, this concern can be largely overcome. The boundary objects available in a digital ecosystem can be used to extend a given digital platform to meet the needs of a particular user or group of users. In theory, these extensions and add-on products can provide limitless flexibility to the users of the ecosystem, thereby making a strong case for adoption.

2. Budget is a blocker: knowing that the construction sector does not spend enough to embrace digital technologies it becomes challenging to convince construction companies to deploy resources to develop custom software or to fully standardize their processes and practices to use off-the-shelf software. Digital ecosystems can help overcome this hurdle. While acting alone is too demanding for most construction companies, working collaboratively—to complement, adjust, and support joint efforts that are essential to leveraging digital ecosystems (Jacobides, Sundararajan, and Van Alstyne, 2019) can make innovation affordable.

3. Heterogeneous software systems and data streams: construction projects depend on a number of collaborating disciplines where the work is interconnected, with a plethora of asynchronous decisions and changes made over the life of the project. While we cannot escape the use of heterogeneous digital tools, the data for the construction project can be streamlined and brought into a Common Data Environment (CDE). Use of CDE can be further enhanced by the availability of a digital ecosystem that supports the development of add-on products.

The application of digital ecosystems in the construction sector is still in its nascent stage. Several issues remain unresolved. Moving forward, the industry, as a whole, must address these issues. Researchers and scholars must build on the theory and knowledge on platforms and ecosystems available in the literature, mostly in other sectors of the economy to promote the use of digital ecosystems in the construction sector. Some of the questions that need to be answered are:

1. How should platform-based ecosystems be designed to address the challenges faced by the industry?
2. How will digital ecosystems transform our industry and contribute to horizontal, vertical, and longitudinal integration?
3. What are the interlinkages between existing data standards such as Industry Foundation Classes (IFC) and digital ecosystems?
4. How can competing digital ecosystems co-exist?
5. How should researchers develop the theory for digital ecosystems in construction?
6. How do digital platforms affect our projects and our profession and influence the future of work in construction?
3.7 Conclusion

Digital ecosystems can lead to the Construction 4.0 transformation and help construction companies become true digital enterprises. With platforms at the core, augmented by digital add-on products and data-enabled innovative tools, digital ecosystems can provide the much needed horizontal, vertical, and longitudinal integration. These digital enterprises can work together with owners, design and engineering firms, suppliers, and other stakeholders in industrial digital ecosystems.

3.8 Summary

- A detailed description of ecosystems and platforms.
- Key characteristics of ecosystems.
- Digital ecosystems in construction.
- Example digital ecosystems in construction.
- Future trends in digital ecosystems and their implication for Construction 4.0

References


