Digitally Constructive Ecosystems

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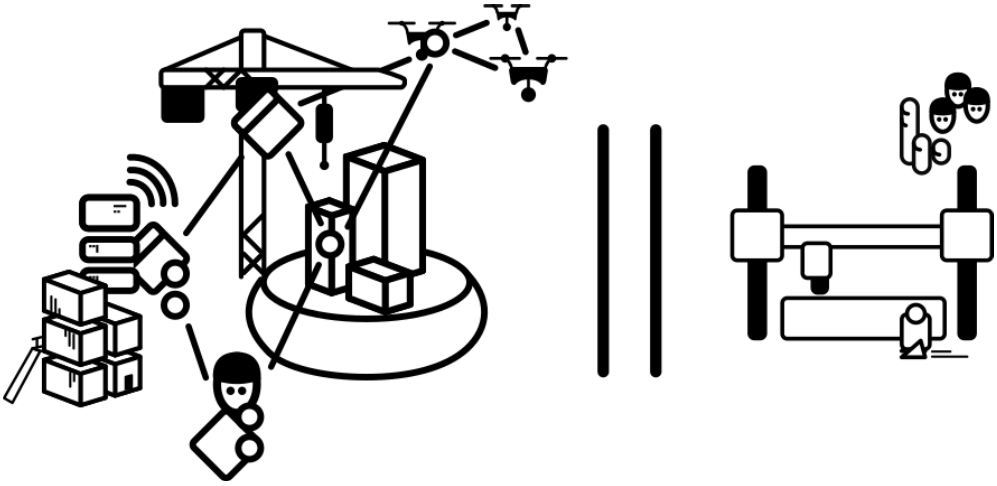
UPPKOPPLAD BYGGPLATS



Digitally Constructive Ecosystems

A glimpse towards a Roadmap for Union Compliant and Digital Constructive Ecosystems powered by Twins surrounding the Construction Site

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As the public sector transition into the digital age, so does the heavily regulated construction industry. How will the construction site become connected, and stay synchronized to the ebb and flow of transactions in digital constructive ecosystems - as prescribed by the new DIGITAL agenda by the European Commission? This white paper provide a glimpse of an internal and collaborative roadmap on the track towards fully connected construction sites, using federated technologies that empower a fragmented industry.

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1 The Challenge

1.1 Background, purpose and need

The current, overarching trend in digital transformation is Industry 4.0 (I40) and the twin transition - a short-circuitry of command within ecosystems of suppliers and consumers, through the leverage of federated Cyber-Physical systems that connect the digital world to the physical. This enable data-driven businesses envisioned to lessen the environmental burden of industry, whilst increasing its efficiency and output.

Due to the substantial needs of more and sustainable housings across Europe, the necessity of resource efficiency and larger productive output, means that the construction industry is also in dire need of such digital transformation. This need of a digital transition is actualised by the sustainability goals set up by the European Green Deal[1], targeting the built environment in particular with the Renovation Wave[2] and Waste Directive[3,4], adding the twin agenda[5] to achieve a Circular Economy[6] and evidence-informed OSH policies[7,8] for a safer constructive work environment. All of these goals are to be target with data-driven analysis and optimisations through a digitalisation of the construction sector, rendering a federated cyber-physical system out of the entire industry, providing a virtualised overview - which through simulations and forecasts, can show the path forward towards a sustainable, more effective and productive constructive environment.

As construction industry exist at the interface between public and private interests, and due to the *traditional* inherent longevity of the construction product - i.e. buildings - construction thus becomes heavily influenced by policies and regulations from public administrations. This means that while most of industry digitise, so does also the public sector, necessitating the construction industry to actively participate in definition of the common digital infrastructure for society.

Therefore, this white paper address the need of an overview of such a joint transformative trend, and how it is relevant for the Construction Industry. The paper provide a top-down connection from the European policy initiatives, relevant for the digital agenda of the construction industry, down to the Swedish authorities acting as the national responsible. Furthermore, the report look at what this all entice for construction at this specific moment of time; here the aim is to provide a current outlook, on the available fields of technologies that has the potential to provide towards the prescribed goals. Finally, we also present the most general first steps necessary to render a digital transformation of business in construction industry.

Specifically, we focus on the European DIGITAL initiative[9], and the plans set out by the Swedish authorities DIGG and Boverket[10,11], while depicting a hierarchy of stakeholders together with the current technologies relevant for the realisation of broadly digital construction industry and sites. Still, as these initiatives are in constant flux, so will also the view presented here have to change over time, in light of emergent technology and incentives.

1.2 The investigative project

The main challenge selected for this project was on how to look forward on what is to come for a connected construction site, and how best to accommodate such sites in practices and by technology within the constructive environment. This spells as a roadmap, but of the more abstract and research oriented form, as to enable an agenda for applied research into digitizing and connecting the construction site within ecosystems of the constructive industry. Essentially, such roadmap has the format of a digression from the collected goals at different stakeholder levels, to the gaps of the required technology, through the known challenges and resulting requirements. Finally, we arrive at a scaffold, for businesses to source in drafting roadmaps, towards implementations within their own operations.

1.3 Method

As the main feature of a roadmap are the goals, and how to get there, we started with looking at what the upcoming requirements are for the construction industry. Since the constructive environment is heavily regulated, it was natural to start at the very top of legislative authorities, namely at the European Commission. As the Commission has published a number of relevant documents, pointing out the upcoming pathway for the construction industry, it was easy to find information on the general goals. This was followed up by a screen on the national level, to see what legislations, and initiatives within the authorities, that connect with the Union goals.

To collect information on the situation at ground, in the daily work of construction actors, the project members participated in meetings and discussions on each test bed. This enabled a more tacit collection of knowledge providing a general picture of the digital situation, and the needs of the industry.

Lastly, I40 was investigated as a topic, which shed light on what other industries with more digital prowess has already achieved, and where they are going now. This revealed what technologies was suited to follow up on the challenges found in the field, and goals set by the Union, as to conclude on an abstract roadmap - as a joint synthesis, delivered from the “Connected Construction Sites” (“Uppkopplad Byggplats”, UB) project.

This project was conducted at Luleå University of Technology, in digital meetings and correspondence within the **academic UB group**. Knowledge has also been shared between this project and the **Smart Built Environment, Datadelning: användarfall**, through meetings on the topic of data sharing within the constructive environment.

The document was drafted using **Free and Libre Open Source Software**.

2 Results from the investigation

2.1 Connecting construction sites through joint efforts on building digital industrial ecosystems for the constructive environment

When rendering the high level goals of the Union at a national level, it becomes evident that adoption of the I40 trend could spur innovation towards Digital Twin technology in a Construction industry dominated by Small- and Medium-sized Enterprises (SMEs). Such adoption can be initiated by building industrial ecosystems through the use of digital copyleft practices and open standardisation of Application Programming Interfaces (APIs). We find that the hihg-level goals driving the constructive environment is set along European Values, centered on a sustainable and circular market, towards a fully digitised industry on a data-focused infrastructure at a large regulatory interface at the national level. While industry fragmentation and organisation heterogeneity has traditionally been a hindrance to innovation and digital uptake, the collaboration of a few large and many smaller players can be a strength if combining copyleft principles with I40 ideas and common open data standards. The path forward for construction industry is thus found to be a combination of multiple techniques and research areas, at different levels of a stakeholder hierarchy, where a sovereign single market for a twin ready industry is glimpsed - through a combination of Machine Learning (ML), Distributed Ledger Technologies (DLT) and Free and Libre Open Source Software and - Hardware (FLOSS and FLOSSH) coordinated through open API standards. Therefore, the objective of a fully digital and twin capable construction industry, is probably best achieved by starting to internally integrate standard digital technology and render more digitally apt industry actors. Such digital integration is eased by also sharing business agnostic experiences, of the transformation process, openly through FLOSS. Then, to tie together the resulting digital capacity, actors should work together on open API standards to join forces in building efficient and sustainable constructive industrial ecosystems.

2.1.1 Constructive goals

A central requirement for an effective and coordinated digitalisation are common and clearly defined goals. To start, the top priorities can be sought at the international level in the collective agenda of the European Union, as can bee seen in (Figure 1). Upon reviewing the top initiatives we find that they are fuelled by value-driven axioms, grounded in European Social Rights[12], with an aim to foster a resource efficient[1] and world-class internal market[13] driven by innovation.[14]

Those European values are to be upheld by rising up to the twin challenge[1], with a resource efficient and Circular economy[6], fostering industrial ecosystems[5] with value in networks of industrial actors, and innovation driven by technology oriented SMEs[15]. As the circular and networked market require a high business connectedness, the Union has put forth the DIGITAL programme[9] to speed digital uptake across public and private sectors, whilst favoring FLOSS to ensure the sovereign use of data-driven technology.[16] This is in accord with the European Pillar of Social Rights[12], through transparent digital services and systems[16] that respect European rights, and by easing adherence to the Occupational Health and Safety framework[7] for construction sites.

Meanwhile, there are additional goals set for the built environment under the Renovation Wave[2], spelling a higher resource efficiency, lower costs and higher production to be achieved in the construction phase, by novel design and operational processes leveraging digital tools.[17] To enable such a transition within construction industry, Swedish authorities has put forth plans for a data-centered[18] digital infrastructure[10], in harmony with its implementation at the large regulatory interface with construction industry.[11] Thus, the understanding of this interface and its stakeholders are of interest for the construction industry - in order to render a path towards digital architectures for constructive ecosystems that are fit for the future.

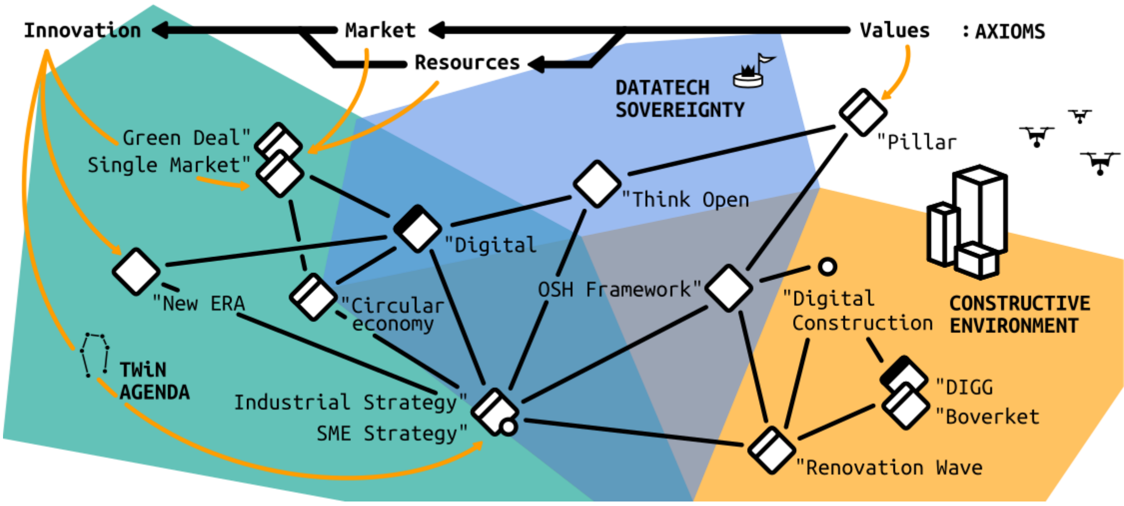

Figure 1 A view of the overarching goals, from the international Union level, down to the goals set in the national Swedish constructive environment. The axioms at the Union level are shown as a conceptual flow from the "Pillar[12] through the aim on a resource efficient "Green Deal[1] in a "Single Market[13] focused on innovation by the "New ERA[14]. At the union level these values are realised in a joint "Industrial-[19] and "SME Strategy[15], following suit with the "Digital[9] transition towards a "Circular Economy[6]. Furthermore, it is expected that everyone adhere to the "Think Open[16] initiative and the “OSH Framework[7] in making a safe and sound "Digital Construction[17] industry, fit with regard to the "Renovation Wave[2]. At a national level, Swedish authorities including "DIGG[10,18] and "Boverket[11] participate in the coordination of the implementation. The general axioms and connected values are illustrated on top with their relations to relevant initiative publications drawn with curved arrows. Publications are shown as nodes, with their size and thickness indicating an arbitrary measure of impact. Initiative and publication relations is indicated by lines, according to the view

presented by this paper, while the colored areas relate the overarching contexts connecting them.

2.1.2 Challenges and stakeholders

The foremost challenge within construction industry is the fragmentation between stakeholders; both at sites, across value chains and between projects.[20] This fragmentation is amplified in combination with the heterogeneity of the corporate construction industry into many SMEs.[21] Such synergies currently limits the incentive, and ability to drive innovation and technology uptake[22,23] - where this lack of digital initiative risks opening the construction industry to predatory business models leveraging vendor lock-in.[24] Yet, this challenge becomes more of an opportunity for faster innovation, should the industry step up to adopt I40 and the twin transition across the value ecosystems, as SMEs has the potential to drive innovation and foster technology uptake in industries.[15,25]

Since an isolated view of the construction site is a contradiction to the objective of a connected site, it becomes useful to view the hierarchy of stakeholders from the connected site all the way up to the Union, whilst highlighting particular opportunities at different levels and by certain aspects in the industrial nomenclature (see Figure 2). Starting at the top, the Union steer along the digital and circular agenda[6,9], to make Life Cycle Analysis (LCA) a tool in decision making and market stimuli, by the collection of renovation passports, sustainability levels and Energy Performance Certificates (EPC) in digital logbooks for construction.[2] Such data will enable policy and law making at legislative levels of member states, to guide the shape of digital construction permit systems and other central regulatory toolkits. Specific data to be used in procurement biddings, judged as necessary for those instruments, include Building Information Modeling (BIM)[11], LCAs and other environmental measures[26]. Further down, to facilitate corporate ecosystems at the business level[5], a fragmented construction industry[21] needs protocols for digital agreements and procedures[27], as well as twin and operational data exchange systems throughout the supply chains.[28] Each participating enterprise also need ways to make use of I40 and the digital twins[19,22], to support upcoming modes of data-driven businesses and regulation[2] based on BIM, transactional, operational, simulated and predicted data.[17] Yet further down the hierarchy, we find challenges with collection and transmission of operational data between the site and its stakeholders, to support control and feedback of machinery and instructions for operator processes.[28] At the physical site, there is a lack of agreed upon architecture for measurement and actuator structures within the Internet-of-Things (IoT) domain, and especially so with respect to interoperability between stakeholders.[27] Furthermore, there is an open field to take up new technology[29] such as drones and robotics in daily operations[17] - with an expected high impact on constructive processes form and output. Adding to the rather mainstream view of capital driven construction sites, there is also further room for novel technology centered ecosystems of various organisations in support of circular business models, who enable crowd funded[14] and decentralised bidding systems over open construction designs.

Since most of these opportunities are in enabling ecosystems of industrial actors to collaborate, their development are probably best realised in joint ventures on R&D, perhaps fully leveraging FLOSS and FLOSSH to ensure vitality and longevity of joint digital infrastructural projects.[24]

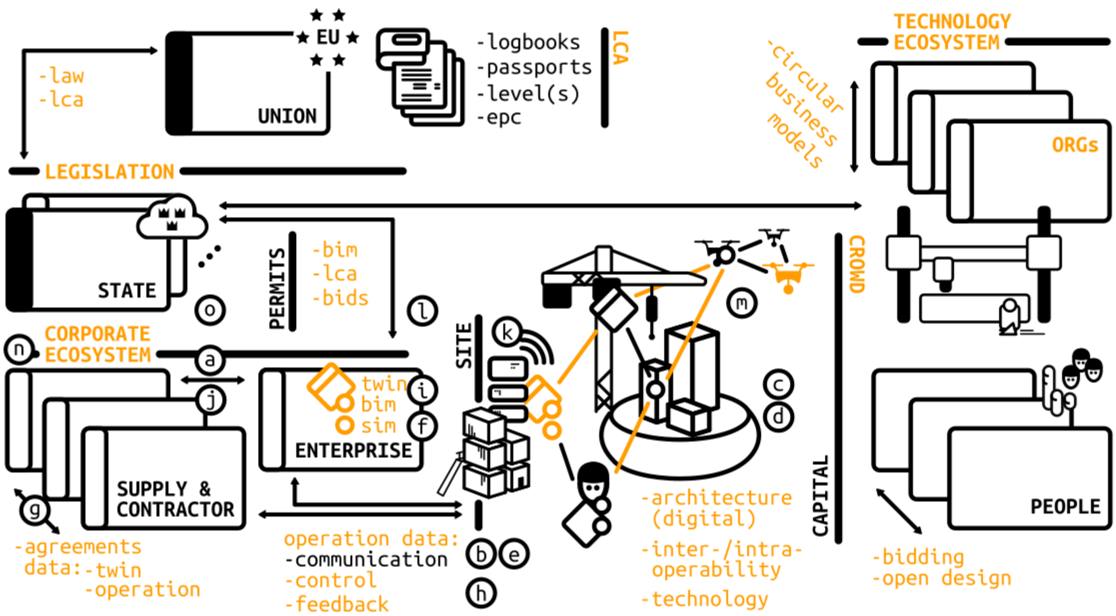

Figure 2 The hierarchy of stakeholders related to the construction site, highlighting particular challenges and the relevant white papers from the UB project that address them in part. Specific challenges are highlighted in orange and itemized using dashes, whilst stakeholders are illustrated with boxes of different thickness depending on complexity. System components and concepts are indicated with smaller boxes and circles. Circles with letters in them indicate approximate position of an UB white paper, as percieved by the author(s) of this paper. The site feature arbitrary technologies, with their interaction

between stakeholders highlighted. For more information on the details, read the second paragraph under *Challenges and Stakeholders* section. Whitepaper key; a)[30] b)[31] c)[32] d)[33] e)[34] f)[35] g)[36] h)[37] i)[38] j)[39] k)[40] l)[41] m)[42] n)[24] o) this white paper

2.1.3 Opportunities on a digital path

With an overview of the goals for the twin transition of the Constructive Environment (Figure 1), and a firm understanding of the current challenges at the site and in the stakeholder ecosystems (see Figure 2), one can collect corresponding technology and research targets into a diagram as in Figure 3.

Notable areas of research and development are *ML* and *Artificial Intelligence* serving to make use of data[43], and *federated learning* which contribute techniques to share the function of data while maintaining its value. *DLT*[9] help assure data integrity, whilst providing decentralised options for trustless design of automated agreements, biddings and decisions. I40 signify various techniques for achieving twin-readiness in ecosystems of stakeholders[44,45], whilst FLOSS and FLOSSH enable transparent and sovereign design of infrastructure and services, necessary to uphold Union social values.[16,46] *Open API standards* make it possible for an ecosystem to freely interact digitally across stakeholder borders, where *BIM* serve to render an effective and purposeful sharing and use of building related data.[17]

As the areas pointed out above are only described briefly, there is also room for targeted surveys in each area on particular available technologies; whilst being a necessary future action, finding and verifying all of those surveys lies far outside of the scope of this white paper. For a more targeted exposition that detail specific IoT related technologies at and around the site, please refer to the sibling white paper “Towards digitalization of construction sites”, also from the UB project.[42]

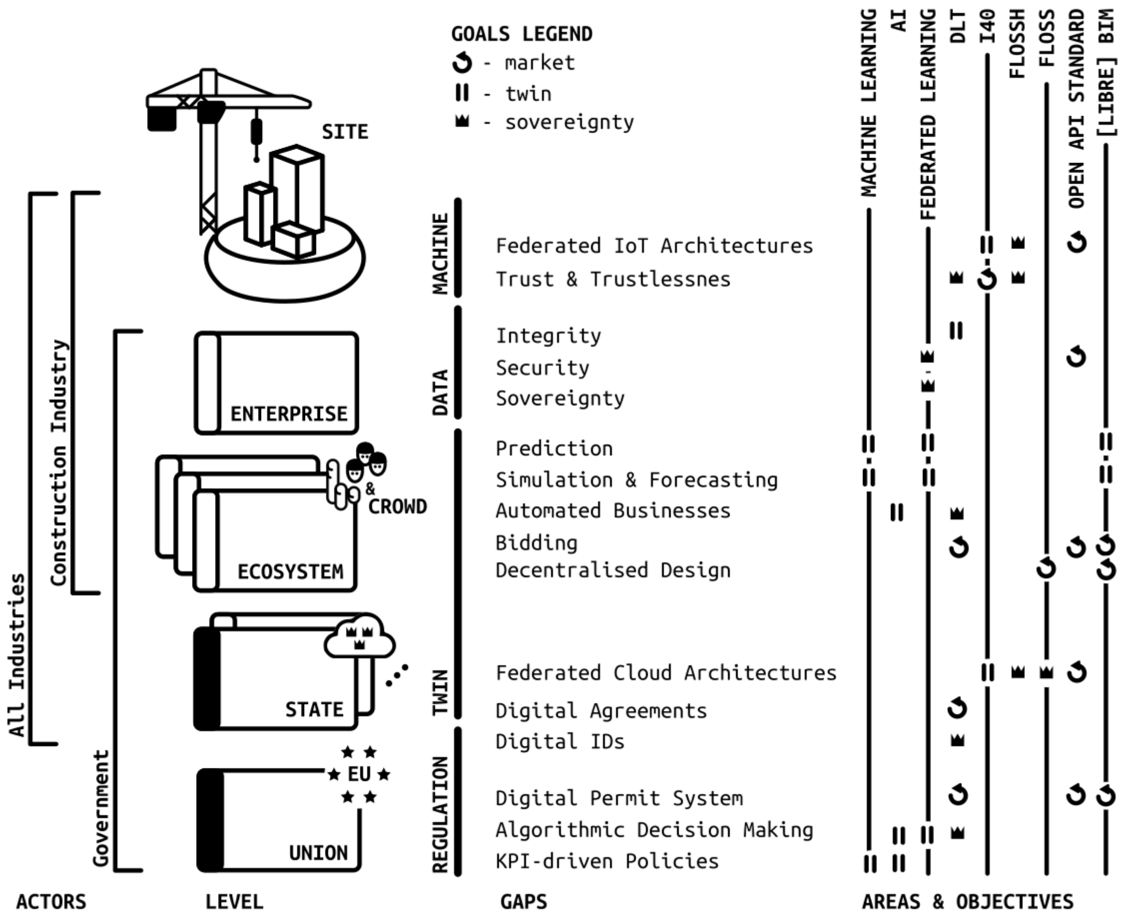

Figure 3 A diagram on how the goal categories broadly relate to gap technology and areas, on the different stakeholder levels, together with an idea on which actors who will find the areas interesting. The levels span from the construction site all the way to the union level; *machine* related gaps are found at the site, *data and twin* in the enterprise and ecosystems levels, while *twin and regulation* finally concern stakeholders at the state and union levels. The goal areas are grouped as **market**) corresponding to an inclusive, circular single market and ecosystems, **twin**) corresponding to the digital transition in general, combined with I40 and twin technologies, while **sovereignty**) relate to transparency, i.e. upholding European values and technological sovereignty. The figure is discussed in the second paragraph of *Opportunities on a digital path* section.

2.2 Effects and notable results

We find that the overarching goals, connect at the level of industrial stakeholders as a number of R&D areas, who are made accessible through the implementation of copyleft digital infrastructure as prescribed by open APIs. The goals described at the Union level start with the axiomatic form of values for a sustainable Europe[1,13] upholding the social rights of its citizens[12] (see Figure 1). These translate into directives on data that need to be shared from member state constructive environments[2], which will serve to kick-start the digitalisation of the construction industries in each member state, as part of the DIGITAL initiative.[9] For the Swedish construction industry, this means more work on adopting digital technology within businesses, whilst developing construction centric APIs[11] to handle the connections from construction sites to operations and between stakeholders (Figure 3). To make this approach tractable to an industry with a manual tradition, construction industry has all to gain from adopting copyleft models such as FLOSS in the implementation of APIs as well as in-house adoption of Infrastructure as a Service (IaaS) cloud technology.[18,24]

2.3 Requirements and challenges

The **digital technology** need to support *architectures that empower ecosystems* with many SMEs participating in the value network. This is true on both the *cloud and things level* of systems; thus, both *federated* cloud technology as well as *federated* IoT are favorable. Furthermore, it is beneficial to put *focus on I40* precepts in implementation of architectures, as this is the general trend emerging from practices proven beneficial in other successful processes to establish industrial ecosystems.

Likewise, **on the operative level**, practices that support *integration of systems from multiple stakeholders* are necessary to enable the collaboration of several actors at and around each construction site. This means that methods for propagating trust, or so called *on-boarding*, of otherwise unaffiliated devices has to happen *in changing constellation* within and between projects and sites.

The **central change in the constructive organisations** is towards a view of *value on the ecosystem level*. This is true for all players, especially so for the larger players at the traditional interface between supply chains, construction sites and end-consumers of the building products. As these actors are *the major gatekeepers* to large scale construction industry today; these actors are those that *are in most danger* from vendor lock-in, and therefore also pose as the largest threat to the constructive environment, should they fail in digital transformation and *end up at the local minima* of vendor lock-in.[47]

3 Experiences from the project

At the **outset of the project**, the ecosystems view was not thoroughly established in the public debate. **During the project**, it became clear that the public sector is actively pushing towards ideas of federated cloud technologies[10] and the twin agenda[5]. Therefore the **scope of a roadmap for the construction site has expanded** to encompass the perspective of the site and its stakeholders, their value chain, together with the public and authorities that the site interact with by association. As the coordination efforts in drafting a twin society are **still on-going**[9,10,14], and the final guidelines are not yet present, means that particular **objectives for the constructive environment might change over time**.

The UB **team worked openly** in sharing information and *collaborating on the joint vision* of a Roadmap. Although the concept of a complete roadmap, from a single point of origin, is infeasible - their efforts has combined into a good start, with a glimpse of the path forward, together with a *plethora of examples* on small steps towards a digital and connected construction site.

4 Conclusion

4.1 Summary

We find that the construction site environment is best described when considering its full interactome; all the way from the site up to authority level. As such, both cloud technology and IoT approaches are necessary to fully render a connected construction site. This is best achieved by following the I40 trend, while designing *federated* architectures along the cloud-to-things continuum, to enable the full participation of the constructive ecosystems of many SMEs. Furthermore, construction industry should start forming these industrial ecosystems today, by binding together their value chains into networks through the use of open APIs, while centering their internal digital systems on data through the use of IaaS cloud technology and IoT.

- The **construction site is not isolated**, but part of a large constructive ecosystem.
- Industrial architectures for the full **cloud-to-things continuum is necessary** for realisation of efficient digital constructive ecosystems.
- **Industry 4.0 should be integrated** in construction, meaning a focus on service oriented architectures and stand-alone micro services.
- Use **open Application Programming Interfaces, knitting together** value networks across stakeholder boundaries
- Deepen internal digitalisation through the use of **IaaS cloud technology to organise** data for use, and **IoT to collect** it.
- Make heavy use of **copyleft models**, to protect the sector from vendor lock-in.

4.2 How can the digital technology be implemented in the project or the enterprise?

The most important step is to realise that **collaboration always trumps competition**; on a global scale, markets compete, and those markets that collaborate internally the most will win over those that do not - man only has to look at herself and her position in nature to know that this is the truth. Once at that understanding, each market actor has to **integrate digital technology** to handle data and information properly in their own processes. This information is then made accessible through treaties **bound to open API definitions** across value ecosystems, as to produce a coherent collaborative model for the other market actors closest to the internal businesses. By association, such an approach will naturally knit together the whole market eventually, with natural ecosystem borders arising *ad-hoc* as gradients of transactional density, achieving a digitally connected and twin-ready **industrial ecosystem by emergence**.

The path can be broadly summarised as the following **SOBIH** model;

- **Strategise** for the participation in value ecosystems, shifting objective from one dimensional value chains to three dimensional producer-and-consumer networks.

- **Organise** digital internal data, information, knowledge and intelligent processes with cloud technology[10]
- **Build** digital ecosystems horizontally by developing joint APIs[11]for digital methods and processes, such as
  - trade/share information and knowledge (ex. BIM) between stakeholders in ecosystem and
  - share knowledge on relevant KPIs (ex. climate data) to authorities
- **Integrate** data collection systematically on the vertical, through IoT deployments and data mining operations, while utilising the data by means of ML (ex. costs, quality and logistics optimisations).
- **Harness** the power of the ecosystem by integrating machine operations horizontally across stakeholder boundaries, using federated cloud technology[10], trustless IoT architectures, digital agreements (ex. DLT-based) and federated learning techniques, to build novel and agile joint businesses - targeted at the digital stage of the market.

4.3 Caveat lector – Risks and issues with digitalisation

The largest risk in digital adoption is the lure into vendor lock-in, which erodes the worth of our society at large. Second to that is the risks with being too late in adoption, when the own business is rendered obsolete. Being an early adopter carry its own economic impact, but is basically a gamble for higher gains, whilst cybersecurity (sovereignty) is something to keep track of throughout the transformation and beyond. Thus, our obvious risks are, from worst at the top;

- Costly, and dangerous digital **vendor lock-in**[47]; see sibling white paper[24], regarding details on the risks and more information on how **FLOSS methodologies** can lessen the risk and impact of lock-in.
- Due to the constant **changes to digital policies**, natural at this onset of our collective digitalisation, industries with a deep interface with public sector will face changes from new trends within digital regulation. This means that;
  - **early adopters** could face large digital **refactoring projects**; opt to use **open design patterns**, to heighten chances of selected model to prevail for the larger

community and regulation, thus lessening the burden of rewriting interfaces and refactoring systems.
   - **late adopters** might suffer severe **market share losses**, due to incapacity to join and influence the form of digital ecosystems early on, becoming **locked-out of profit** in new digital construction models.
- **Sovereignty loss**, by design or through misconfiguration of systems, is a constant headache in IT; and so it will be throughout the digital transformation. Take extra precautions to apply **RAS**;
   - *Resilience*; **Virtualise** systems into micro services on IaaS cloud technology
   - *Agility*; Apply **Continuous Deployment** practices to support iterative development, testing and quick redeployments
   - *Security*; Be **mindful of licenses**, as to allow systematic scrutiny and independent audit of security standards implemented in systems.[24]

4.4 Take away

The focal point of connecting the construction site should be to render industrial ecosystems within the constructive environment; executed along the Union agenda on the Twin Transition[5] and innovative[15] circular market[13]. Therefore;

- The construction site, and the whole construction industry, has a large interface with the constructive ecosystem and public sector respectively; this necessitates architectures that support I40 enabled federated cloud and IoT technology.
- Early adopters have much to win by influencing the rise of industrial ecosystems and adopting critical digital technologies - through copyleft collaboration on open APIs for ecosystems, reference implementations for internal systems and standards for free flow of data; whilst also preventing vendor lock-in.

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