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Construction 4.0

Paul A. Adekunte[1], Matthew N. O. Sadiku[2], Janet O. Sadiku[3]

[1]International Institute of Professional Security, Lagos, Nigeria
[2]Roy G. Perry College of Engineering, Prairie View A&M University, Prairie View, TX, USA
[3]Juliana King University, Houston, TX, USA

ABSTRACT

Construction 4.0 is the modern method of construction referred to as the digital transformation of the construction industry, driven by the adoption of advanced technologies to improve efficiency, quality, and sustainability. This is a concept inspired by Industry 4.0, which focuses on the digital integration of manufacturing processes. Construction 4.0 aims at leveraging technology to optimize all stages of the construction lifecycle, from design and planning to construction and operation – the next revolution in the construction industry. This paper delves into looking at the pros and cons in Construction 4.0, solutions to the challenges, and what its future holds for humanity.

KEYWORDS: *Construction 4.0, ubiquitous connectivity, Internet of Things (IoT), figital twins, additive manufacturing (AM), cloud computing, cyber-physical systems (CPS), building information modeling (BIM), sensors, drones, embedded robotics and automation, monitoring systems*

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INTRODUCTION

While the Building Information Modeling (BIM) approach has been an important enabler for the digital transformation in construction, the concept of Construction 4.0 gradually begins to impose itself, as shown in Figure 1. It is still difficult today to give a precise definition, even if the experts are unanimous on the fact that it will be a major revolution for the industry [1]. Despite the lack of international consensus on what the concept of Construction 4.0 really means, some authors define it as a pure and simple instantiation on the concept of Industry 4.0 in construction (that is, the use of ubiquitous connectivity technologies for real-time decision-making), others see it as a means of finding a coherent complementarity between the main emerging technological approaches in the construction industry. Still, others see it as a more encompassing approach that goes beyond the simple technology framework to best meet the industry's current challenges [1], as shown in Figure 2.

However, regardless of the definition given to it, the big change brought by Construction 4.0 seems to revolve around a decentralized connection between the physical space and the cyberspace via ubiquitous connectivity, and with the presence of the human as necessary to manage and maintain this link [1].

Construction 4.0 refers to the integration of advanced digital technologies into the construction industry, inspired by the principles of Industry 4.0, as shown in Figure 3. It marks a significant shift from traditional methods toward more intelligent, automated, and connected processes. This transformation aims to address long-standing industry challenges such as inefficiency, high cost, delays, and safety concerns [2].

HISTORICAL OVERVIEW OF CONSTRUCTION 4.0

History shows that industrial revolutions tend to have a slow starting pace, but with time, have a galloping impact on shaping common production technologies, everyday lifestyles, etc [3], as shown in Figure 4. Generally, the term industrial revolution can be defined as a widespread dramatic change in the methods of producing goods and services [4]. Like the previous, i.e., the first and second industrial revolutions, the third industrial revolution, (3IR) was also driven by technological advances regarding manufacturing, distribution, and energy factors [3]. In

the first industrial revolution, it was the printing press, the second industrial revolution it was radio and television, and while in the 3IR, it is/was the combined power of computing, telecommunications, and news broadcasting [5].

With respect to the 3IR technologies, six major high-technology agents among others were identified, which are: microprocessor, computer-aided design and manufacturing (CAD/CAM), fiber optics, biogenetics, lasers, and holography [6]. There was also the development of microelectronics technology at this historical junction [7, 8], for its importance to the immense impact on the affordability of computing power.

Furthermore, the historical development of Construction 4.0 is as follows [9-12]:

1. **Pre-Construction 4.0 Era (Before 2000s):**
- Manual & Analog Processes: This was when the construction industry was largely dependent on manual labour, paper-based documentation, and traditional project management techniques.
- Mechanization & CAD: The introduction of mechanized equipment and Computer-Aided Design (CAD) in the 1980s and 1990s laid the groundwork for digitalization.

2. **Transition Phase (2000-2010)**
- BIM Emergence: It was in the early 2000s that Building Information Modeling (BIM) began to gain attention, offering a 3D model-based process that improves collaboration and project outcomes.
- The U.S. General Services Administration (GSA) started mandating BIM in 2003 for federal projects.
- Early Automation: During this period, the use of project management software like Primavera and MS Project became common.

3. **Construction 4.0 Emergence (2011-2019)**
- Inspired by Industry 4.0: The term "Industry 4.0" was introduced in Germany in 2011, and the construction sector began adapting similar principles.
- Technology integration:
  - Drones, IoT, robotics, and AI started being integrated into the construction workflow.
  - Cloud computing enabled real-time collaboration on construction sites.
- Digital Twin Concepts and Smart Construction Sites started to gain traction.

4. **Construction 4.0 Expansion (2020-Present)**
- COVID-19 as a catalyst: The pandemic accelerated the adoption of digital technologies due to remote work needs and labor shortages.
- Advanced Automation: This is in areas of:
  - Robotics and 3D printing now being used in building components.
  - Predictive analytics and machine learning are applied for maintenance, scheduling, and risk assessment.
- Sustainability & Smart Cities: Construction 4.0 supports green building practices and smart infrastructure planning.

THE BENEFITS/IMPACTS OF CONSTRUCTION 4.0

Construction 4.0 is known to offer numerous benefits and impacts, as shown in Figure 5 on humanity by the transformation of the construction industry in various ways such as [13-18]:

- Rendering faster project delivery: Since automation reduces construction time, it will enable projects to be completed more quickly and efficiently.
- Lower costs: Resource use is optimized through the use of AI and predictive analytics, reducing waste and minimizing costs.
- Enhanced safety: IoT wearables monitor worker health and risks, thereby improving site safety and reducing accidents.
- Sustainable construction: Digital twins and smart systems help reduce carbon footprints, hence promoting eco-friendly building practices.
- Better quality control: Helps in reducing errors as VR and AV enable clients and developers to visualize and inspect buildings before construction starts.
- Improved productivity: Robotics and automation transform construction processes, increasing/enhancing efficiency and precision.
- Reduced risks: Digital twins and VR review and help identify potential issues before construction begins, reducing costly reworks and financial risks.
- Increased/enhanced collaboration: Cloud-based platforms and Building Information Modeling (BIM) facilitate real-time collaboration and data sharing among stakeholders.
- Environmental sustainability: The optimizing of the use of resources cum minimizing waste contributes to greener building practices.
- Innovative design: 3D printing and prefabrication enable rapid prototyping and innovative designs.
- Improved working conditions: Automation reduces the physical burden of labor-intensive tasks, hence creating a safer working environment.

KEY TECHNOLOGIES IN CONSTRUCTION 4.0

Some of the key technologies in Construction 4.0 are:

1. **Building Information Modeling (BIM):** This facilitates the creation and management of digital representations of physical and functional aspects of construction projects, enhancing collaboration and decision-making across the project lifecycle [19].
2. **Internet of Things (IoT):** The IoT devices enable real-time monitoring of construction sites by collecting data on machinery, materials, and worker movements, thereby improving safety and operational efficiency [20].
3. **Artificial Intelligence (AI) and Machine Learning (ML):** These technologies support predictive analytics, risk management, and optimization in project planning and execution [21], as shown in Figure 6.
4. **Robotics and Automation**: Robotics are increasingly being used for repetitive or hazardous tasks such as bricklaying, welding, or concrete printing, to help in improving precision and reducing labor demands [22].
5. **Drones and Unmanned Aerial Vehicles (UAVs):** They are used for site surveys, progress monitoring, and safety inspections, offering high-resolution aerial imagery and real-time data [23].
6. **Augmented Reality (AR) and Virtual Reality (AR):** Both AR and VR enhance visualization and training, allowing stakeholders to engage with designs interactively and identify potential issues before construction begins [24], as shown in Figures 7 and 8.
7. **Additive Manufacturing (AM) or 3D Printing: AM** helps to minimize the supply chain in the construction industry through autonomous production of building components directly from digital models without human intervention and complicated formworks. 3D Printing also known as additive manufacturing, offers a cost-effective and rapid solution for producing components or even entire buildings [25, 26], as shown in Figures 9 and 10.
8. **Cloud Computing**: This enables centralized data storage, improved collaboration, and efficient project management [27].
9. **Cyber-Physical Systems (CPS):** CPS is an application to meet the objective of escalating productivity in construction projects, and as well as to address the recurrent problems in the construction industry. It also links the virtual and physical worlds, simplifying construction data gathering and reporting, and lowering risks [28, 29], through the use of actuators, sensors, IoT, robots, cobots, and drones, as shown in Figures 11 and 12.
10. **Blockchain**: Blockchain in Construction 4.0 plays a transformative role via enhancing transparency, traceability, trust across project lifecycles, digital identity and access management, with its challenges of scalability and performance, interoperability, regulatory issues, cost and complexity [30, 31], as shown in Figure 13.

CHALLENGES FACING CONSTRUCTION 4.0 AND SOLUTIONS

There are several challenges facing Construction 4.0 that hinder its adoption and implementation. Some of the key challenges and potential solutions are [2, 18, 32-37]:

The challenges include:

1. Lack of knowledge and expertise: Insufficient technical knowledge and expertise in digital technologies, as well as the lack of skilled workforce (i.e. skills gap) to operate advanced digital tools like BIM, AI systems, or robotics pose significant challenge.
2. Lack of digital strategies and supporting leadership: The lack of effective synergies in working relationships and poor long-term strategic planning can hinder the successful implementation of Construction 4.0.
3. Cybersecurity and data protection: Data and cybersecurity concerns must be properly addressed, and stringent security standards must be put in place to protect sensitive information from cyber-attacks and data breaches.
4. Data fragmentation: Lack of collaboration and data fragmentation prevent the optimal use of smart technologies.
5. Unsuitable framework: Existing frameworks may not be suitable for adopting digital technologies, hence hindering the transition to Construction 4.0.
6. Interoperability and integration issues: Different technologies and systems may not be compatible, leading to data silos and inefficiencies. The lack of common standards exacerbates this issue.
7. Resistance to change: Organizational and cultural resistance to change is very common, particularly in traditional construction firms that are wary of adopting disruptive technologies.
8. Regulatory and legal uncertainties: The legal framework for digital tools, data ownership,

liability in automated decision-making, and cross-border data usage is still evolving.

Some of the solutions would include:

1. Develop digital literacy: This is by providing training and education to construction professionals to develop the necessary skills and knowledge to adopt Construction 4.0 technologies, as shown in Figure 14.
2. Strategic planning and leadership: Encourage leaders to develop and implement digital strategies that support the adoption of Construction 4.0 technologies.
3. Implement robust cybersecurity measures: Need to develop and implement robust cybersecurity measures to protect sensitive information and prevent data breaches, as shown in Figure 15.
4. Improve data management: Implement data management systems that enable seamless data sharing and collaboration among stakeholders.
5. Develop suitable frameworks: Develop and adopt frameworks that support the adoption of digital technologies and Construction 4.0 principles.

Some of the key Construction 4.0 technologies that can be used to address these challenges and as earlier discussed in the paper would include:

- Building Information Modeling (BIM)
- Artificial intelligence (AI)
- Internet of Things (IoT)
- Virtual Reality (VR) and Augmented Reality (AV)
- 3D Printing and Prefabrication

CONCLUSION

Construction 4.0 is paradigm shift towards smarter, more sustainable, and highly efficient construction practices. By embracing and leveraging automation, digital tools/technologies, and data analytics, the industry can improve safety, reduce costs, accelerate timeliness, and minimize environmental impact. However, it also presents challenges/limitations such as the need for workforce re-skilling, high initial investments in technology, cybersecurity issues, and overcoming industry-wide resistance to change, among others. Overcoming these challenges and limitations can position and revolutionize the industry for long-term growth and transformation.

More information on Construction 4.0 can be obtained from books in [38-40] and in the following journals:

- *Journal on Construction Innovation*
- *Journal on Automation in Construction*

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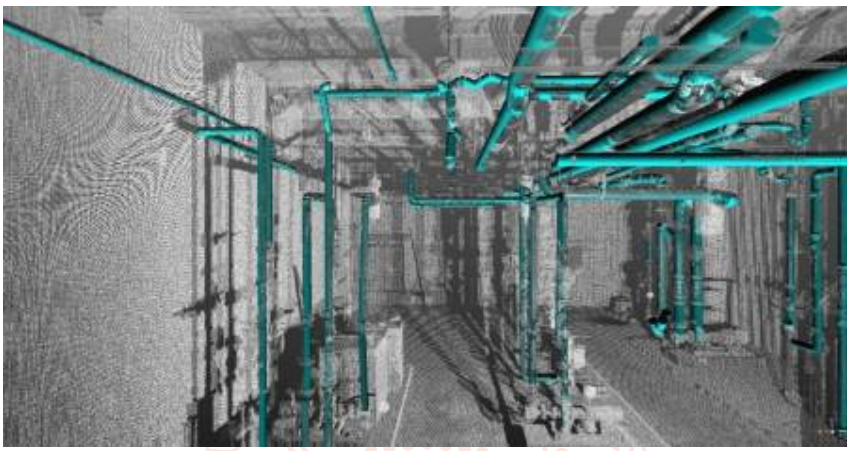

Figure 1 Building Information Modeling (BIM).

Source:https://www.google.com/search?q=images+of+BIM+in+construction+4.0+by+wikipedia&sca_esv=f37af7071d948b3e&udm=2&biw=1036&bih=539&sxsrf=AHTn8zq5eekfKsLjrpED-ZBy-J-V2u2NLg%3A1747738845718&ei=3WAsaJ_PK9eQkdUPjeWEwAY&ved=0ahUKEwjfsbzI8rGNAxVXSKQEHY0yAWgQ4dUDCBE&oq=images+of+BIM+in+construction+4.0+by+wikipedia&gs_lp=EgNpbWciLmltYWdlcyBvZiBCSU0gaW4gY29uc3RydWN0aW9uIDQuMCBieSB3aWtpcGVkaWFli4ABUOUPWP45cAF4AJABAJgBjwWgAe4PqgEJMi0yLjAuMi4xuAEMyAEAAEBmAIAoAIAmAMAiAYBkgcAoAfhAbIHALgHAMIHAMgHAA&sclient=img#vhid=EUnhVkyVtxkKkM&vssid=mosaic

Figure 2. Construction

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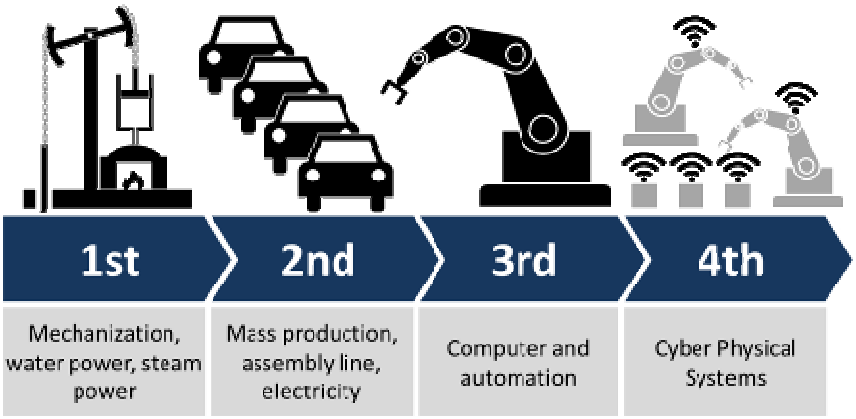

Figure 3. Industry 4.0.png

Source:https://www.google.com/search?sca_esv=e293ca8d199e0e1f&sxsrf=AHTn8zrmAXaMaYtnsq8S4PQ3GsxUi_bTIQ:1747687952764&q=images+on+construction+4.0+by+wikipedia&udm=2&fbs=ABzOT_CWdhQLP1FcmU5B0fn3xuWpAdk4wpBWOGsoR7DG5zJBkzPWUS0OtApxR2914vrjk7XZXfnfKsaRZouQANLhmphfsaRlDNPoWc6rCumaYm3VojqsiuBofLuYVqeJuzeVFrArtYn8anrtQg9oucHCeTR27yMHxAF31k9lv_a8NXq9Jk1mNfGFUy8ZFut1MXrV1vBhNe7WnE43Sd7e7305krgzHUJQw&sa=X&ved=2ahUKEwjHgun8tLCNAxWPV0EAHRZRCuAQtKgLegQIGBAB&biw=1036&bih=539&dpr=1#vhid=SLV6jurA-AMh-M&vssid=mosaic

Figure 4, Industrial Revolution

Source:https://www.google.com/search?sca_esv=e293ca8d199e0e1f&sxsrf=AHTn8zrmAXaMaYtnsq8S4PQ3GsxUi_bTIQ:1747687952764&q=images+on+construction+4.0+by+wikipedia&udm=2&fbs=ABzOT_CWdhQLP1FcmU5B0fn3xuWpAdk4wpBWOGsoR7DG5zJBkzPWUS0OtApxR2914vrjk7XZXfnfKsaRZouQANLhmphfsaRlDNPoWc6rCumaYm3VojqsiuBofLuYVqeJuzeVFrArtYn8anrtQg9oucHCeTR27yMHxAF31k9lv_a8NXq9Jk1mNfGFUy8ZFut1MXrV1vBhNe7WnE43Sd7e7305krgzHUJQw&sa=X&ved=2ahUKEwjHgun8tLCNAxWPV0EAHRZRCuAQtKgLegQIGBAB&biw=1036&bih=539&dpr=1#vhid=9RZ7-PuU_66L1M&vssid=mosaic

Figure 5. Fourth Industrial Revolution

Source:https://www.google.com/search?q=images+on+how+to+prepare+for+construction+4.0+by+wikipedia&sca_esv=18d1df816f52c143&udm=2&biw=1036&bih=539&sxsrf=AHTn8zrKUXnzp-

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Figure 6. Artificial intelligence in Construction 4.0

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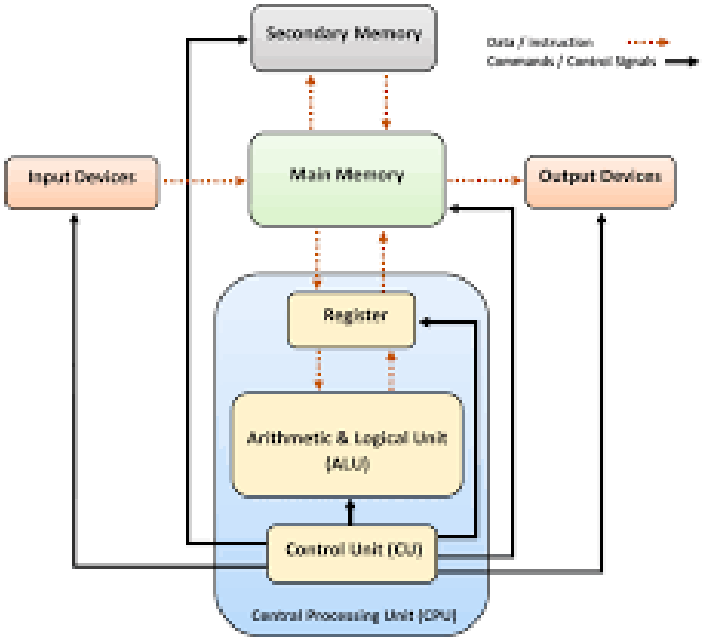

Figure 7. Computer Architecture

Source:https://www.google.com/search?q=images+on+how+to+prepare+for+construction+4.0+by+wikipedia&sca_esv=18d1df816f52c143&udm=2&biw=1036&bih=539&sxsrf=AHTn8zrKUXnzpWTzEpOB4ytkHR7aZQgpg%3A1747737567000&ei=3lssaIvnPOTqhbIPirKJsAU&ved=0ahUKEwiLzt3m7bGNAxVkdUEAHQpZAlYQ4dUDCBE&oq=images+on+how+to+prepare+for+construction+4.0+by+wikipedia&gs_lp=EgNpbWciOmltYWdlcyBvbiBob3cgdG8gcHJlcGFyZSBmb3IgY29uc3RydWN0aW9uIDQuMCBieSB3aWtpcGVkaWFI2JEBULULWNhycAF4AJABA5gBgQgAb1IqgERMC4xLjUuMS4wLjEuMS4xLjO4AQzIAQD4AQGYAgCgAgCYAwCIBgGSBwCgB9EEsgcAuAcAwgcAyAcA&sclient=img

Figure 8. Outline of Construction

Source:https://www.google.com/search?q=images+on+how+to+prepare+for+construction+4.0+by+wikipedia&sca_esv=18d1df816f52c143&udm=2&biw=1036&bih=539&sxsrf=AHTn8zrKUXnzpWTzEpOB4ytkHR7aZQgpg%3A1747737567000&ei=3lssaIvnPOTqhbIPirKJsAU&ved=0ahUKEwiLzt3m7bGNAxVkdUEAHQpZAlYQ4dUDCBE&oq=images+on+how+to+prepare+for+construction+4.0+by+wikipedia&gs_lp=EgNpbWciOmltYWdlcyBvbiBob3cgdG8gcHJlcGFyZSBmb3IgY29uc3RydWN0aW9uIDQuMCBieSB3aWtpcGVkaWFI2JEBULULWNhycAF4AJABA5gBgQgAb1IqgERMC4xLjUuMS4wLjEuMS4xLjO4AQzIAQD4AQGYAgCgAgCYAwCIBgGSBwCgB9EEsgcAuAcAwgcAyAcA&sclient=img

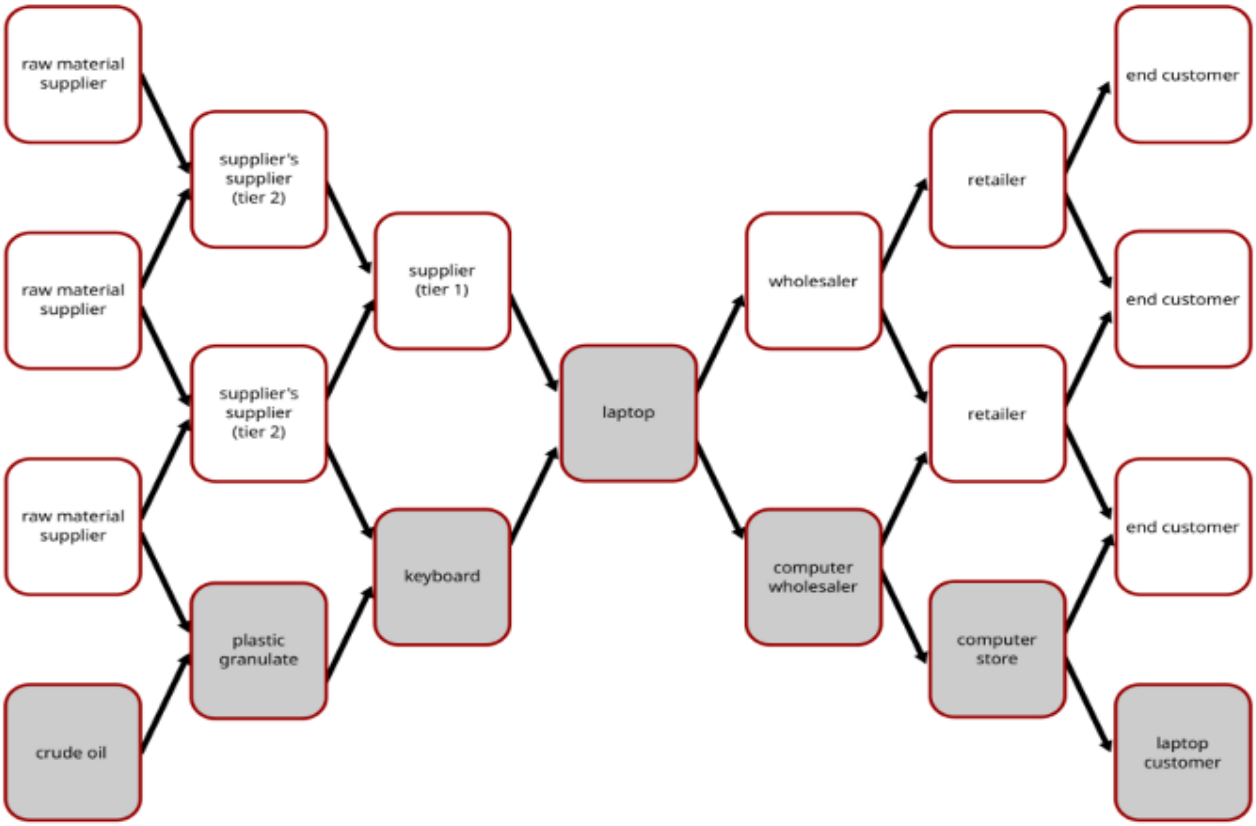

Figure 9. Supply chain management

Source:https://www.google.com/search?q=images+of+blockchain+in+construction+4.0+by+wikipedia&sca_esv=f37af7071d948b3e&udm=2&biw=1036&bih=539&sxsrf=AHTn8zqF4j2ShOo907LStvdKqQsAyRmWMA%3A1747739744919&ei=YGQsaJf1N_CThbIPwChiQ4&ved=0ahUKEwiXpZ_19bGNAxXwSUEAHUNwKOEQ4dUDCBE&oq=images+of+blockchain+in+construction+4.0+by+wikipedia&gs_lp=EgNpbWciNWltYWdlcyBvZiBibG9ja2NoYWluIGluIGNvbnN0cnVjdGlvbiA0LjAgYnkgd2lraXBlZGlhSOWzAVCQDViBfnABeACQAQCYAZMUoAGTOKoBDTItMi42LTEuMS4wLjK4AQzIAQD4AQGYAgCgAgCYAwCIBgGSBwCgB5YCsgcAuAcAwgcAyAcA&sclient=img#vhid=fwKlN_tqTRhtRM&vssid=mosaic

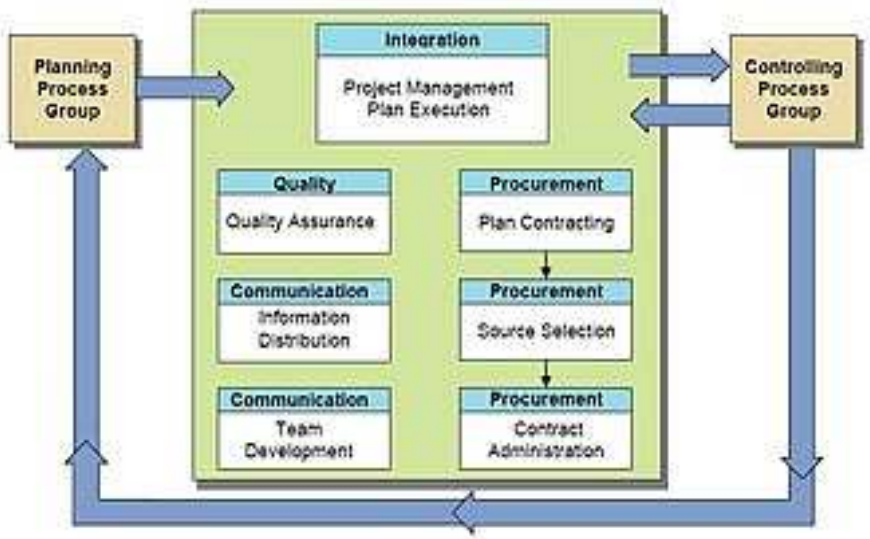

Figure 10. Project management

Source:https://www.google.com/search?q=images+of+construction+4.0+implementation+plan+by+wikipedia&sca_esv=f37af7071d948b3e&udm=2&biw=1036&bih=539&sxsrf=AHTn8zq2byURC2TkrY1__hnJa41GyrZVVw%3A1747740124226&ei=3GUsaIXLDanU7M8Pwa6zoQs&ved=0ahUKEwiFqY6q97GNAxUpKvsDHUHXLLQQ4dUDCBE&oq=images+of+construction+4.0+implementation+plan+by+wikipedia&gs_lp=EgNpbWciO2ltYWdlcyBvZiBjb25zdHJ1Y3Rpb24gNC4wIGltcGxlbWVudGF0aW9uIHBsYW4gYnkgd2lraXBlZGlhSMDuAlDeDVjsrAJwAXgAkAEDmAGcNKAB68EBqgEPMi00LjUtMi4yLjIuMS41uAEMyAEAAEBmAIBoAILwgIHECMYJxjJApgDAIgGAZIHATGgBgFsgcAuAcAwgcDMi0xyAcG&sclient=img#vhid=xPwres6oM_sT1M&vssid=mosaic

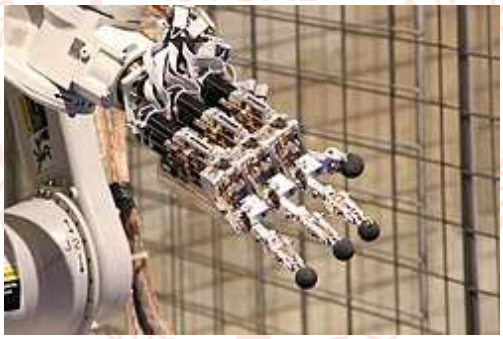

Figure 11. Robotics

Source:https://www.google.com/search?q=images+of+robotics+in+construction+4.0+by+wikipedia&sca_esv=f37af7071d948b3e&udm=2&biw=1036&bih=539&sxsrf=AHTn8zpTdMvdd7AyqCsI7iphCClq8dtsg%3A1747739110429&ei=5mEsaLjyGaygkdUPs923iQ4&ved=0ahUKEwi4_djG87GNAxUsUKQEHbPuLeEQ4dUDCBE&oq=images+of+robotics+in+construction+4.0+by+wikipedia&gs_lp=EgNpbWciM2ltYWdlcyBvZiByb2JvdGljcyBpbiBjb25zdHJ1Y3Rpb24gNC4wIGJ5IHdpa2lwZWRpYUiggFQ1wpYxkVwAXgAkAEAmAHAAqAB0xSqAQYyLTEwLjG4AQzIAQD4AQGYAgGgAhLCAgcQIxgnGMkCmAMAiAYBkgcBMaAH9wOyBwC4BwDCBwMzLTHIBw0&sclient=img#vhid=KnUc4KrMQiTffM&vssid=mosaic

Figure 12. Cobot

Source:https://www.google.com/search?q=images+of+cobots+in+construction+4.0+by+wikipedia&sca_esv=f37af7071d948b3e&udm=2&biw=1036&bih=539&sxsrf=AHTn8zqQUvCRDyEfxg04rse5pSEAcrMw%3

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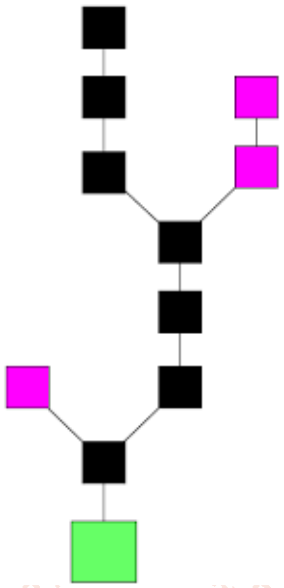

Figure 13. Blockchain

Source:https://www.google.com/search?q=images+of+blockchain+in+construction+4.0+by+wikipedia&sca_esv=f37af7071d948b3e&udm=2&biw=1036&bih=539&sxsrf=AHTn8zqF4j2ShOo907LStvdKqQsAyRmWMA%3A1747739744919&ei=YGQsaJf1N_CThbIPwChiQ4&ved=0ahUKEwiXpZ_19bGNAxXwSUEAHUNwKOEQ4dUDCBE&oq=images+of+blockchain+in+construction+4.0+by+wikipedia&gs_lp=EgNpbWciNWltYWdlcyBvZiBibG9ja2NoYWluIGluIGNvbnN0cnVjdGlvbiA0LjAgYnkgd2lraXBlZGlhSOWzAVCQDViBfnABeACQAQCYAZMUoAGTOKoBDTItMi42LTEuMS4wLjK4AQzIAQD4AQGYAgCgAgCYAwCIBgGSBwCgB5YCsgcAuAcAwgcAyAcA&sclient=img

Figure 14. Interchange (road)

Source:https://www.google.com/search?sca_esv=e293ca8d199e0e1f&sxsrf=AHTn8zrmAXaMaYtnsq8S4PQ3GsxUi_bTIQ:1747687952764&q=images+on+construction+4.0+by+wikipedia&udm=2&fbs=ABzOT_CWdhQLP1FcmU5B0fn3xuWpAdk4wpBWOGsoR7DG5zJBkzPWUS0OtApxR2914vrjk7XZXfnfKsaRZouQANLhmphfsaRlDNPoWc6rCumaYm3VojqsiuBofLuYVqeJuzeVFrArtYn8anrtQg9oucHCeTR27yMHxAF31k9lv_a8NXq9Jk1mNfGFUy8ZFut1MXrV1vBhNe7WnE43Sd7e7305krgzHUJQw&sa=X&ved=2ahUKEwjHgun8tLCNAxWPV0EAHRZRCuAQtKgLegQIGBAB&biw=1036&bih=539&dpr=1#vhid=yIpgerDVjveX0M&vssid=mosaic

Figure 15. Cybersecurity and infrastructure

Source:https://www.google.com/search?q=images+of+construction+4.0+cybersecurity+plan+by+wikipedia&sca_esv=f37af7071d948b3e&udm=2&biw=1036&bih=539&sxsrf=AHTn8zqIIRhF4ZE653EvOMJYmfpBSR_nIw%3A1747741224132&ei=KGosaK_mB9Lo7_UPtZqHuAc&ved=0ahUKEwivmsu27GNAxVS9LsIHTXNAXcQ4dUDCBE&oq=images+of+construction+4.0+cybersecurity+plan+by+wikipedia&gs_lp=EgNpbWciOmltYWdlcyBvZiBjb25zdHJ1Y3Rpb24gNC4wIGN5YmVyc2VjdXJpdHkgcGxhbiBieSB3aWtpcGVkaWFIAFAAWABwAHgAkAEAmAEAoAEAqgEAuAEMyAEAmAIAoAIAmAMAkgcAoAcAsgcAuAcAwgcAyAcA&sclient=img#vhid=5WZnXOWt5RCDhM&vssid=mosaic