

The innovativeness of innovations

Danijel Rebolj

Professor Emeritus, University of Maribor

Abstract

The importance of innovation has always been important for the economic growth and the quality of life of the humankind. But in the latest years the awareness of its importance is growing and has led to systematic study of the process and the characteristics of innovation. The paper is first giving an overview of the science of innovation, partly with the help of an innovation, the Artificial Intelligence. Then the paper focuses on differences in the level of innovation and tries to explain them by comparing innovative solutions to a well-known problem from the field of construction.

Keywords

Levels of innovation • case study • automated construction progress monitoring • Artificial intelligence

Introduction

In his book *The web of life*¹, Fritjof Capra systematically develops the conclusion that the basic meaning of life is cognition. Or in other words, cognition is the very process of life. Certainly, living beings are at different levels of complexity and thus on different levels of cognition, whereby Capra closely connects, in a way even equates cognition with the mind.

The main driver for the development of cognition, or the evolution of mind, are challenges, that the environment, which in most cases are other living beings, poses before us. Reactions to most challenges are coded into us either genetically², which represents the experiences of our ancestors, or through our own experiences, which begin from the very early days of our existence as living beings. But there are situations, where the coded »rescue manual« does not help. And for such situations we need to develop new solutions. The new solutions can be a combinations or alterations of existing ones, or they can be something completely new, an idea »never seen before«. We call such new ideas innovations. But what exactly is innovation and how to distinguish a good one from a bad one. In other words, what is the level of an innovation or the innovativeness of an innovation. Terwilliger in his blog³ defines three levels of innovation: incremental, breakthrough and transformational. Other authors have defined other metrics and proposed different approaches to innovation⁴.

In this paper we will first elaborate further on the science of innovation, whereby we will use one of the latest innovations to create the overview automatically. Then we will focus on a problem for which several innovative solutions have been proposed. We will present some solutions and then analyze them based on the disruption to the process flow, estimated efficiency, and estimation of required additional costs.

The science of innovation

Throughout the history, there are many known cases of innovative ideas that emerged in an instant in the minds of great artists, engineers, and scholars, such as Da Vinci, Edison, or Einstein. But in fact, the instant emerging, the »quantum leap«, has had a long process before it.

1 Fritjof Capra, "The web of life: A new scientific understanding of living systems." (1997).

2 ENCODE, Project Consortium "An integrated encyclopedia of DNA elements in the human genome." *Nature*, no. 489/7414 (2012): 57–74. Doi:10.1038/nature11247.

3 Jay Terwilliger, "The Three Levels of Innovation." (2015). Available at: <https://www.creativerealityies.com/innovationist-blog/bid/49954/the-three-levels-of-innovation>.

4 E.g. Charles Edquist, "The Systems of Innovation Approach and Innovation Policy: An account of the state of the art." DRUID conference in Aalborg (2001).

† Corresponding author: Danijel Rebolj

E-mail: danijel.rebolj@um.si

Open Access. © 2023 Danijel Rebolj, published by Sciendo

 This work is licensed under the Creative Commons Attribution-NonCommercial-NoDerivs 4.0 License.

The greatest innovators have developed their own methods that led to a creative process of innovation. In recent times, these methods have been systematically studied and developed further, which formed the basis of the new field of science of innovation. For although the core concepts of inventive designs are too often unknown and even surprising, they are also feasible and can be learned, leading to potentially patentable designs⁵.

Some definitions of innovation require new ideas, methods, products, services, or solutions to have a significant positive impact and value⁶, however, the positiveness is almost impossible to quantify (as for example in the well-known case of Alfred Nobel's invention of dynamite). In most cases the positiveness of an innovation depends on how people use it (as in the example of gunpowder), or what undesired effects emerge only later (as in the case of DDT, which became infamous for its environmental impacts).

One of the greatest innovations that will undoubtedly »change everything«, is the idea and especially the latest development and application of artificial intelligence. The experts' discussions about its influences on mankind are very diverse and its positiveness is quite unclear. AI can among others help to analyze and summarize various scientific topics, like in the following request to Google's Bard⁷ to Elaborate on the science of innovation. The response is useful, thus, we have included it in this article. To distinguish it from the author's own text, it is written in *Italic*. References created by Bard were included in the list at the end of the paper. They are not always reliable, but we left them as created to give the reader an impression on Bard's reliability.

Innovation, the process of creating new or improved products, services, or processes, is a complex phenomenon driven by a multitude of factors, including scientific breakthroughs, technological advancements, market demands, and entrepreneurial spirit. While innovation often appears as a sudden breakthrough, it is often the culmination of years of research, experimentation, and problem-solving⁸.

The history of innovation is replete with examples of scientific breakthroughs that have ignited transformative innovations. The discovery of penicillin by Alexander Fleming in 1928 revolutionized modern medicine, leading to the development of antibiotics that have saved countless lives⁹. Similarly, the invention of the transistor in 1947 by John Bardeen, Walter Brattain, and William Shockley ushered in the era of electronics, paving the way for the development of computers, smartphones, and numerous other technological marvels¹⁰.

Despite the transformative power of innovation, it is not without its challenges. One of the primary obstacles to innovation is the uncertainty and risk associated with developing new products, services, or processes¹¹. The lack of clear market demand, the high cost of research and development, and the potential for failure can deter individuals and organizations from pursuing innovative endeavors¹².

Another challenge to innovation is the inherent inertia within established industries and organizations. Established companies may be reluctant to disrupt their existing business models or invest in unproven technologies, potentially stifling innovation¹³. Additionally, the competitive landscape of industries can discourage innovation, as companies may focus on protecting their market share rather than venturing into uncharted territories¹⁴.

Despite the challenges, there are strategies that can be employed to foster innovation. Creating an environment that encourages risk-taking and experimentation is crucial¹⁵. This can be achieved by providing funding for research and development, promoting open innovation models, and fostering a culture of creativity and collaboration.

5 Tomasz Arciszewski, "Inventive engineering: Knowledge and skills for creative engineers." (2016).

6 Nick Jain, "What is Innovation? Definition, Types, Examples and Process." (December 12, 2023). Available at: <https://ideascale.com/blog/what-is-innovation/>.

7 Google Bard (December 22, 2023). Available at: <https://bard.google.com/>.

8 Peter F. Drucker, "Innovation and entrepreneurship." (1985).

9 Alexander Fleming, "On the antibacterial action of cultures of a penicillium, with special reference to their use in the isolation of B. influenzae." *British Journal of Experimental Pathology*, no. 10/3-4 (1929): 226-236.

10 John Bardeen, Walter Houser Brattain and William Shockley, "The transistor, a semiconductor triode." *Bell System Technical Journal*, no. 27/7 (1948): 727-738.

11 Joseph A. Schumpeter, "The theory of economic development." (1934).

12 Michael L. Tushman and Philip Anderson, "Technological discontinuities and organizational environments." *Administrative Science Quarterly*, no. 31/3 (1986): 439-465.

13 Clayton M. Christensen, "The innovator's dilemma: When new technologies cause great firms to fail." (1997).

14 Michael E. Porter, "Competitive strategy: Techniques for analyzing industries and competitors." (1980).

15 Drucker, "Innovation and entrepreneurship."

Additionally, establishing effective mechanisms for knowledge sharing and collaboration across disciplines can accelerate innovation¹⁶. This can be facilitated through cross-functional teams, industry-academia partnerships, and knowledge networks that connect experts from diverse fields¹⁷.

The science of innovation is a complex and dynamic field that is constantly evolving. While scientific breakthroughs have played a pivotal role in driving innovation, it is essential to address the challenges that hinder progress. By cultivating a supportive and innovative environment, we can foster breakthroughs that will shape the future.

Case study

To better understand innovation and its implications, we will analyze innovative solutions to a well-known problem from the field of engineering, more specifically, construction. We will try to determine the level of innovation of observed solutions, which complements the well-known input and output metrics¹⁸.

Construction industry is extremely interested in accurate information on the progress of the construction project¹⁹. Especially when a project is behind schedule, managers need to get information about delayed activities as soon as possible to be able to react quickly and adapt the project schedule plan to new circumstances. Consequences in not doing so can have cascading effects and extend the project beyond the contractual deadlines, which results in the payment of significant penalties. In an ideal case, managers would have a real-time overview of the construction progress on the level of schedule plan activities. Traditional manual methods, however, are often time-consuming, prone to errors, and lack the ability to provide real-time data insights, while automated continuous monitoring and control in all phases of a project are still beyond the feasibility of existing technologies that would also fit construction project budgets.

Therefore, the demand for an economically sustainable and efficient solution is great, which encourages research in this area. The construction industry has witnessed the emergence of several promising automated methodologies for progress monitoring, each with unique characteristics and applications. These methodologies can be broadly categorized into four main categories.

Computer vision (CV) techniques are gaining significant prominence due to their ability to extract meaningful information from images and videos²⁰. CV methods typically involve capturing high-resolution images or videos, employing image processing and object detection algorithms to accurately identify and track construction elements, and comparing the as-built conditions with the planned progress to assess the project's status. CV-based methods typically involve regular data capture and processing, often on a daily or weekly basis, to monitor progress over time. The frequency depends on project complexity and the desired level of detail. Technology used includes cameras, image processing algorithms and object detection algorithms.

Laser scanning and photogrammetry techniques enable the creation of highly precise 3D representations of construction sites²¹. These methods capture dense point clouds or 3D models that serve as accurate representations of the project's geometry. By analyzing changes in these 3D models over time, stakeholders can track progress and identify potential issues. Laser scanning and photogrammetry methods involve periodic data capture, often utilizing drones or mobile platforms. The frequency depends on project size and the desired level of accuracy and is typically weekly or monthly. Technology Used includes Laser scanners, photogrammetry software and 3D modeling software.

The integration of Internet of Things (IoT) sensors into construction sites is rapidly expanding²². IoT sensors collect real-time data on various parameters, including concrete temperature, structural strain, and material inventories. This data provides valuable insights into project progress, enabling the detection of anomalies, optimizing resource allocation, and ensuring compliance with safety regulations. IoT sensors continuously collect data, which is then analyzed and visualized in real-time

16 Ikujiro Nonaka, Hirotaka Takeuchi and Katsuhiro Umemoto, "A theory of organizational knowledge creation." *International Journal of Technology Management*, no. 10/7-8 (1995): 833-845.

17 Ashish Arora, Andrea Fosfuri and Alfonso Gambardella, "Markets for technology: The economics of innovation and corporate strategy." (2001).

18 Enkel, E.-J., Gassmann E., and Henkel, J. "Measuring innovation performance: A review of innovation metrics and their impact on innovation practices." *R&D Management*, no. 39/3 (2009): 213-229.

19 Marianna Kopsida, Ioannis Brilakis and Patricio Antonio Vela, "A review of automated construction progress monitoring and inspection methods." *Proceedings of the 32nd International Conference of CIB W78* (2015):421-431.

20 Varun Kumar Reja, Quang Ha, Koshy Varghese, "Computer Vision – Based Construction Monitoring." *Automation in construction*, no. 138 (2022): 1-18.

21 Mani Golparvar-Fard, Jeffrey Bohn, Jochen Teizer, Silvio Savarese and Feniosky Peña-Mora, "Evaluation of image-based modeling and laser scanning accuracy for emerging automated performance monitoring techniques." *Automation in construction*, no. 20/8 (2011): 1143-1155.

22 Arka Ghosh, David John Edwards and M. Reza Hosseini, "Patterns and trends in Internet of Things (IoT) research: future applications in the construction industry." *Engineering, Construction and Architectural Management*, no. 28/2 (2021): 457-481.

or near real-time. The monitoring frequency can be continuous or near real-time and depends on sensor type and the desired monitoring granularity.

Digital twins represent virtual replicas of physical construction projects²³. These digital models are populated with real-time data from sensors, laser scans, and other sources, enabling continuous comparison between the as-built and as-planned conditions. This real-time feedback loop allows for proactive identification of potential issues, enabling corrective actions to be taken promptly, and facilitating the simulation of alternative scenarios to optimize project outcomes. Digital twins continuously update their models based on incoming data, providing a real-time representation of the project's status. This allows for proactive identification of potential issues, facilitating informed decision-making, and enabling the simulation of alternative scenarios to improve project outcomes.

Apart from the well-known four categories, there is yet another view on automatic construction progress monitoring based on the way changes are detected. Almost all known methods follow the principle of traditional progress monitoring, which is an overview of the construction status at a given moment. This can be either on a daily, weekly or any other basis, but in general, the complete construction site needs to be inspected in order not to miss any change, made from the previous inspection. Although latest technologies were used in automation of the monitoring process, these innovations did not break away from linear development. At the same time, they cause significant additional costs that do not outweigh the positive economic effects. According to Terwilliger they would fall into the category of incremental innovations²⁴.

The IoT and Digital twins categories do, however, represent breakthrough innovations. The Digital twins solutions actually include IoT as they are based on sensor data, but they are both in early conceptual stages and will also require significant additional costs for owners and for the construction companies. These circumstances will only allow to use the IoT and Digital twins on very few construction projects.

The only other solution, we are aware of, is, however, based on a different, simple consideration that every change occurs before the eyes of a worker or a machine²⁵. All changes are constantly perceived and as-built model continuously updated during the construction process, instead of periodical scanning of the whole building under construction. Low precision 3D scanning devices, which are closely observing active workplaces, are sufficient for correct identification of the built elements. Such scanning devices are small enough to fit onto workers' protective helmets and on the applied machinery. In this way, workers capture all workplaces inside and outside of the building in real time. The built in mobile processing unit analyses each point cloud frame to identify as-designed building elements within the point cloud, then sends the element identifiers to a server. The server collects all identified already built elements and compares the 4D as-built digital model and the 4D as-designed model to identify differences between both models and thus the deviations from the time schedule. The differences are reported in near real-time, which enables efficient project management. The used technological components are simple and the system economically and technically feasible with a wearable device not exceeding 100€ per helmet.

Conclusion

The case study is showing that almost all innovations in the observed problem area are technology driven, meaning that innovators did not look beyond the linear development, but just added technology to improve the process. Solutions based on computer vision as well as those based on 3D scanning require additional work and equipment for taking photographs, videos or 3D scans, or they require special drones for the same task. Except additional costs this will also introduce disruptions of the construction process. If performed during night, other problems occur (e.g. additional workforce, sophisticated drones / robots etc.).

Solutions based on IoT seem better integrated into the construction process, but they require all elements of the building, including the smallest among them (e.g. parts of electrical installations) to become smart elements. It is quite questionable whether such approach will become feasible in a foreseeable future. The same concern applies to solutions based on digital twins.

The fact is that so far investors and construction companies are still waiting for a feasible solution of automated construction progress monitoring system. It is acceptable that economical aspects and effectiveness are not a priority with experimental

23 Yue Pan and Limao Zhang, "A BIM-data mining integrated digital twin framework for advanced project management." *Automation in Construction*, no.124 (2021): 103564.

24 Terwilliger, "The Three Levels of Innovation."

25 Zoraz Pučko, Nataša Šuman and Danijel Rebolj, "Automated continuous construction progress monitoring using multiple workplace real time 3D scans." *Advanced Engineering Informatics*, no. 38 (2018): 27-40. Doi.org/10.1016/j.aei.2018.06.001

solutions, it is, however, our view that all aspects of an innovative solution shall be considered from the very early stage of design.

The solution proposed by Pučko et al. introduces no disruption on the construction process, no additional work, and little additional costs²⁶. There are, however, other kind of problems. Although it is supported by the university innovation office as well as by an international technology hub, it cannot get enough financial support for a breakthrough. At the end it would not be the only good innovation to die for lack of support. An open mind, which can look beyond obvious solutions, is a requirement, but not the only one for an innovation to become transformative. For an innovation breakthrough, all aspects must match.

References

- Arciszewski, Tomasz. "Inventive engineering: Knowledge and skills for creative engineers." (2016).
- Arora, Ashish, Fosfuri Andrea, and Gambardella, Alfonso. "Markets for technology: The economics of innovation and corporate strategy." (2001).
- Bardeen, John, Brattain, Walter Houser, and Shockley, William. "The transistor, a semiconductor triode." *Bell System Technical Journal*, no. 27/7 (1948): 727-738.
- Capra, Fritjof. "The web of life: A new scientific understanding of living systems." (1997).
- Christensen, Clayton M. "The innovator's dilemma: When new technologies cause great firms to fail." (1997).
- Drucker, Peter F. "Innovation and entrepreneurship." (1985).
- Edquist, Charles. "The Systems of Innovation Approach and Innovation Policy: An account of the state of the art." DRUID conference in Aalborg (2001).
- ENCODE, Project Consortium "An integrated encyclopedia of DNA elements in the human genome." *Nature*, no. 489/7414 (2012): 57–74. Doi:10.1038/nature11247.
- Enkel, E.-J., Gassmann E., and Henkel, J. "Measuring innovation performance: A review of innovation metrics and their impact on innovation practices." *R&D Management*, no. 39/3 (2009): 213-229.
- Fleming, Alexander. "On the antibacterial action of cultures of a penicillium, with special reference to their use in the isolation of B. influenzae." *British Journal of Experimental Pathology*, no. 10/3-4 (1929): 226-236.
- Ghosh, Arka, Edwards, David John, and Reza Hosseini, M. "Patterns and trends in Internet of Things (IoT) research: future applications in the construction industry." *Engineering, Construction and Architectural Management*, no. 28/2 (2021): 457-481.
- Golparvar-Fard, Mani, Bohn, Jeffrey, Teizer, Jochen, Savarese, Silvio, and Peña-Mora, Feniosky. "Evaluation of image-based modeling and laser scanning accuracy for emerging automated performance monitoring techniques." *Automation in construction*, no. 20/8 (2011): 1143-1155.
- Google Bard (December 22, 2023). Available at: <https://bard.google.com/>.
- Jain, Nick. "What is Innovation? Definition, Types, Examples and Process." (December 12, 2023). Available at: <https://ideascale.com/blog/what-is-innovation/>.
- Kopsida, Marianna, Brilakis, Ioannis, and Vela, Patricio Antonio. "A review of automated construction progress monitoring and inspection methods." *Proceedings of the 32nd International Conference of CIB W78* (2015):421-431.
- Nonaka, I., Takeuchi, H., and Umamoto, K. "A theory of organizational knowledge creation." *International Journal of Technology Management*, no. 10/7-8 (1995): 833-845.
- Pan, Yue, and Zhang, Limao. "A BIM-data mining integrated digital twin framework for advanced project management." *Automation in Construction*, no.124 (2021): 103564.
- Porter, Michael E. "Competitive strategy: Techniques for analyzing industries and competitors." (1980).
- Pučko, Zoran, Šuman, Nataša, and Rebolj, Danijel. "Automated continuous construction progress monitoring using multiple workplace real time 3D scans." *Advanced Engineering Informatics*, no. 38 (2018): 27-40. Doi.org/10.1016/j.aei.2018.06.001
- Schumpeter, Joseph A. "The theory of economic development." (1934).
- Terwilliger, Jay. "The Three Levels of Innovation." (2015). Available at: <https://www.creativerealities.com/innovationist-blog/bid/49954/the-three-levels-of-innovation>.
- Tushman, Michael L., and Anderson, Philip. "Technological discontinuities and organizational environments." *Administrative Science Quarterly*, no. 31/3 (1986): 439-465.

²⁶ Pučko, Šuman, Rebolj, "Automated continuous construction progress monitoring using multiple workplace real time 3D scans."