Theory of Digital (Layered) Technical Systems

By:

Atabak.Monsefi

A master's Thesis

Submitted to the Department of Engineering and Management

Under the Supervision of prof. **MARCO CANTAMESSA**

Politecnico di Torino

September 2023

Agenda

1. Introduction to the Theory of Digital (Layered) Technical Systems

1.1 The Spectrum of Architectural Issues
1.2 A Brief Overview of the Overall Themes
1.3 The Art of Open Design: Promoting Collaboration and Creativity
1.4 Balance Act: Contribution and Control in Platform Strategies
1.5 Fostering Innovation in the Digital Economy.
1.6 An Architectural Blueprint for the Digital Age
1.7 An Appeal to Action in a World That Is Rapidly Changing

2. Theoretical Foundations of Layered Systems

2.1. The Importance of Layering
2.1.2. Modularity and Abstraction
2.2. Layering's Historical Evolution
2.2.1. Early Computer Systems
2.2.2. The Development of Layered Architectures

2.3. Theoretical Foundations of Layering in Different Domains

2.3.1 Software Engineering

2.3.2. Operating Systems

2.4. Formal Notations and Models

2.4.1. Formal Methods

2.4.2. Petri Nets

2.5. Layered architectures' advantages and benefits

2.5.1. Extensibility and Modifiability

2.5.2. Interoperability

2.5.3. Debugging and troubleshooting

2.5.4. Reusability

2.6. Challenges and Things to Think About

2.6.1. Overhead

2.6.2. Being rigid

2.6.3. Overengineering

3: Applications and Case Studies

3.1. A Layered Architecture for Real-Time Systems.

3.2. An Open Architecture for Robot Entertainment

3.3. Interactive Smart Classroom System Using Beacon Technology

3.4. An Example of an Evolving Modular Layered Architecture in Digital Innovation Is the Instrument Cluster in a Car

3.5. Implementing Layered Modular Architecture in Digital Innovation: The Case of the Car's Driver Information Module

3.6 Automated Driving in Real Traffic: Architectural Perspectives from Current Technical Approaches

3.7. Quantum Computing Layered Architecture

4.1. The Significance of Technological Platforms

4.2. The Duality of Platform Governance

4.3. Generative Capacity: Fostering Innovation

4.4. Architecture in Manufacturing Systems.

4.5. Coordination and Adaptation

5.1. Digital Innovation: Definitions and Characteristics

5.2. The Dual Regimes of Digital Innovation Management

5.3. Beyond Technology: Societal Implications

4: Proposals and a Real-World Application

5: Conclusion

6. Reference

Chapter 1:

Introduction to the Theory of Digital (Layered) Technical Systems

Introduction

The delicate interaction between architecture and innovation takes center stage in the ever-accelerating growth of technology. Our exploration of the Theory of Digital (Layered) Technical Systems, a conceptual framework that goes beyond conventional architectural design, begins with this chapter. The area we will be exploring covers a wide range of architectural themes, including real-time systems, robot entertainment, smart classrooms, platform strategies, quantum computing, computer-integrated manufacturing systems, and digital innovation. Although each of these domains represents a distinctive aspect of the digital world, they are all united in the pursuit of efficient architectural design by a common set of guiding principles and frameworks that lay underlying their outward diversity.

1.1 The Spectrum of Architectural Issues

Before starting this exploration, we must recognize our theory's wide range of architectural subjects. These subjects illustrate the wide-ranging effects of digital technology on the society. The interrelated domains that make up the present technology landscape are not isolated islands.

The variety is astounding. For instance, real-time systems power vital applications in industries as diverse as banking, healthcare, and aviation, making them the lifeblood of contemporary civilization. In contrast, robot amusement aims to reinvent how people and robots interact, paving the path for cutting-edge entertainment. Smart classrooms foresee a future in which technology transforms teaching, and quantum computing reveals the enormous potential of quantum mechanics that can be exploited for super-computing. While digital innovation serves as a ray of hope for businesses trying to traverse the rough waters of the digital economy, platform strategies, and computer-integrated manufacturing systems investigate the dynamics of business and industry in the digital era.

1.2. A Brief Overview of the overall Themes

As we prepare for our investigation, a theme from earlier articles becomes apparent that will serve as our compass: the importance of layering in architectural design. This idea is present throughout the wide range of architectural issues that we have included. The conceptual framework of layering serves as a pillar of support for improving complex systems' organizational structure, scalability, and flexibility. The conceptual framework of layering serves as a pillar of support for improving complex systems' organizational structure, scalability, and flexibility.

We see the resounding focus on the significance of layered systems in the publications "A Layered Architecture for Real-Time Systems" and "Layered Architecture for Quantum Computing." These articles present a scenario in which each layer of a system performs a distinct task while harmoniously interacting with surrounding levels to jointly accomplish a more significant goal. In addition to streamlining the development process, this layering strategy gives systems the adaptability and durability they need to succeed in the fast-paced digital environment.

1.3. The Art of Open Design: Promoting Collaboration and Creativity

A new era of collaborative invention is brought in by openness, which acts as a catalyst for innovation and collaboration. Think about how open design may be used, for instance, in the field of robotic entertainment. The importance of openness in the development of robot entertainment systems is emphasized in several publications about the Theory of Digital Layered Technical Systems (TDLTS). In this situation, open design invites the ideas of various developers, opening the door for a group effort that fosters creativity and speeds up progress.

Open design has benefits that go well beyond the world of entertainment. It represents a revolution in the way we think about and carry out architectural design. Encouraging a wide range of stakeholders to take part in the co-creation of solutions that go beyond individual skills, it redefines the conventional bounds of innovation.

1.4. Balance Act: Contribution and Control in Platform Strategies

The digital age's primary force, platform tactics, offers a complicated dynamic that requires a careful balancing act. On the one hand, keeping control over a platform is necessary to guarantee consistency and quality. On the other hand, allowing access to the platform might encourage innovation by accepting outside input. Throughout the history of digitalization, there has always been an emphasis on the requirement of managing the platform's core while allowing external innovation to flourish.

Furthermore, there are a lot of resources that provide organizations with a strategic roadmap through the implementation of the boundary resources model. With the help of this approach, they may successfully negotiate the complexities of platform management and find a happy medium between upholding internal control and welcoming outside input.

1.5. Fostering Innovation in the Digital Economy.

The topic of innovation management is another recurrent thread that runs across technical articles. Innovation is the lifeblood of businesses looking to succeed in an unpredictable world where digital disruption is the norm. Yoo et al. (2010), Svahn and Henfridsson (2012), and Hron (2021) are the authors of the works that explore the complexities of innovation management in the digital economy.

Yoo et al. (2010) emphasize the shifting paradigms that support creative practices in the digital era and introduce us to the new organizing logic of digital innovation. Svahn and Henfridsson (2012) explore the use of dual systems in managing digital innovation, highlighting the complexity of innovation in modern organizations. The continual search for novel theoretical frameworks that might enlighten the future in the terrain of digital creation is also explored by Hron (2021).

1.6. An Architectural Blueprint for the Digital Age

Overall, there has been an emphasis on the inherent worth of layering as an organizational structure since the beginning of the new era of digitalization, the revolutionary potential of open design, the tricky balance between control and participation in platform strategies, and the necessity of innovation management in a technologically advanced society. Additionally, these themes stress how crucial it is to match user experience and corporate objectives in architectural design. Technology serves as a tool to help organizations accomplish their larger strategic objectives.

1.7. An Appeal to Action in a World That Is Rapidly Changing

The importance of internalizing these concepts cannot be emphasized in the rapidly changing technology world of today. We are at the beginning of a digital revolution as designers, engineers, and inventors. The systems we create and the solutions we develop have a significant impact on business, society, and humankind. We must use the ideas of layering, open design, platform strategies, and innovation management as our compass if we are to effectively negotiate this terrain.

Overall, the development of digital systems has brought about a time in which everything like devices, data, and processes are all interconnected. This paradigm shift has resulted in the creation of complex technical systems that smoothly integrate many levels of functionality and abstraction to accomplish broad objectives. TDLTS offers a coherent paradigm for understanding the dynamics of layered systems across many areas by drawing influence from fields such as systems theory, network theory, and computer science.

The challenges involved in designing and managing digital layered technological systems have come to the fore in an era where they are more and more ingrained in our daily lives and enterprises. A systematic strategy that considers both macro-level interactions and micro-level behaviors is necessary due to the complex interplay between several layers, each of which has unique functions and features. This thesis attempts to address these issues by investigating the theoretical underpinnings of TDLTS, its real-world implementations, and the organizational effects it ought to have on producers. In the end, it aims to demonstrate how TDLTS can fundamentally alter how we conceptualize and design sophisticated digital systems.

The scope of this thesis includes a thorough investigation of the fundamental ideas behind layered technological systems, a review of their real-world applications, and a consideration of the implications they have for the development of technology. The following portions of this thesis are as follows:

- In Chapter 2, "Theoretical Foundations of Layered Systems," topics such as abstraction, modularity, and the interplay between layers are examined as the fundamental tenets upon which layered technological systems are built.
- Chapter 3: Applications and Case Studies.A thorough examination of practical uses of layered systems, including those in the telecommunications, software engineering, and distributed computing industries, the implication of the design of digital systems, and its impact on the organization of the companies that are going towards TDLTSs, through case studies.
- Chapter 4: Our article will conclude by exploring an application of TDLTSs, as well as future considerations and problems.

Chapter 2

Theoretical Foundations of Layered Systems

Understanding the theoretical foundations of layered architectures is crucial in the world of digital (layered) technological systems. Complex digital systems are developed using layering as the cornerstone, which is a key architectural element. The theoretical underpinnings of layered systems are thoroughly explored in this chapter, which also clarifies the fundamental ideas, historical backdrop, and fundamental tenets that support this architectural paradigm. We provide the stage for understanding layering's practical uses and ramifications in numerous technological fields by diving into its theoretical foundations.

2.1. The Importance of Layering

A layered architecture's fundamental organizing concept is the division of a complicated system into independent, self-contained layers, each of which has a unique set of functions and interfaces. Each layer builds on the services offered by lower levels and provides abstractions to upper layers in order to achieve a more general goal. This division of labor makes it easier to build modularly, encourages system adaptability, and makes maintenance and scaling less complicated.

2.1.1. The OSI Model: An Innovative Example

The OSI (Open Systems Interconnection) paradigm is a prominent example of how layered systems function in the field of computer networking. The OSI model, created by the International Organisation for Standardisation (ISO), was first presented as a theoretical framework for comprehending and standardizing network communications in the late 1970s.

Seven levels make up the OSI model, each having well-defined functions and interfaces. It moves via the physical, data connection, network, transport, session, presentation, and application levels, starting with the physical layer that is in charge of sending raw bits. This layer hierarchy creates a distinct separation of responsibilities and makes it easier for various networked systems to communicate with one another.

2.1.2. Modularity and Abstraction

The idea of abstraction is one of the cornerstones of layered structures. Each layer encapsulates complicated functionality behind well-defined interfaces and shows a condensed picture of the services it provides to upper levels. By insulating upper levels from the implementation specifics of lower ones, this abstraction enables the autonomous growth and evolution of each layer.

Another important notion is modularity, which is strongly related to abstraction. It is innately possible to accomplish modularity by breaking a system up into layers. Developers may concentrate on one layer at a time by using each layer as a separate module with a specified function, which makes system design and maintenance easier.

2.2. Layering's Historical Evolution

Layered systems have their roots in the early years of computers. A key principle in computer science is the notion of decomposing a difficult issue into more manageable parts. But as technological systems became more complicated, layered structures began to take on a formal shape that we now recognize.

2.2.1. Early Computer Systems

Early computing systems were rather basic, sometimes just having one processor unit and a few auxiliary devices. The demand for increasingly complex and integrated systems increased as technology developed.

2.2.2. The Development of Layered Architectures

A new method of system design was required with the introduction of computer networks and distributed systems in the middle of the 20th century. As these systems became more sophisticated, the concept of layering started to gain popularity as a solution.

An important turning point in the development of layered architectures was the OSI model, which was previously discussed. Although the concept was first designed for networking, its ideas were applicable outside of this field. It served as a model for breaking down complicated systems into manageable levels, influencing later technological advancements in other industries.

2.3. Theoretical Foundations of Layering in Different Domains.

Layered architectures have evolved beyond their networking origins to become a common design model in many fields. Understanding the theoretical underpinnings of layering in these situations offers helpful insights into how to use it practically.

Software Engineering 2.3.1

Layered architectures are frequently used to structure software systems in the field of software engineering. The development process is made easier by the separation of responsibilities made possible by layers, which also encourages code reuse and improves maintainability. The display, business logic, and data access architectural levels of a web application are common examples.

2.3.2. Operating Systems

Layered architectures are frequently seen in operating systems, the foundational software that controls hardware resources and offers services to programmes. Examples of layers in an operating system include the kernel, device drivers, system libraries, and user interfaces. This layered approach separates user-level software from hardware-specific functions to guarantee stability and portability.

2.3.3. Hardware Design

The ideas of layering are used even at the hardware level. For example, layers are employed in the design of integrated circuits (ICs) to create complicated systems. An IC's physical architecture generally consists of layers for power distribution, connectors, and logic gates. The chip's overall functioning is influenced by each layer.

2.4. Formal Notations and Models

Formal models and notations have been created to help clarify the theoretical un derpinnings of layered systems.

These models offer a mathematical foundation for thinking about and analyzing

layered architectural structures.
The formal definition of layered systems using formal techniques is one exampl e of this concept.

2.4.1. Formal Methods

A collection of mathematical approaches known as formal methods are used to describe, create, and validate hardware and software systems. The structure, behavior, and interactions between the layers of layered systems may all be defined using formal techniques.

Layered architectures have been thoroughly described using formal modeling languages, such as the Z notation and the Specification and Description Language (SDL). The functions and interfaces of each layer may be properly specified by architects and engineers thanks to these languages.

2.4.2. Petri Nets

A mathematical modeling technique called Petri nets has also been used to depict layered systems. Petri nets offer a visual and mathematical framework for simulating the operation of distributed and concurrent systems. Petri nets can be used to model interactions between layers, state changes, and potential performance bottlenecks in layered systems.

2.5. Layered architectures' advantages and benefits

The extensive use of layered structures in several disciplines is well justified by their theoretical underpinnings. Layering has a number of different benefits that improve the effectiveness, dependability, and maintainability of complex systems.

2.5.1. Extensibility and Modifiability

Layered systems are naturally expandable and customizable. Modifications or enhancements to one layer can be done with little effect on the other layers since each layer is contained and abstracted from the others. This flexibility makes it easier to update software, add new features, and scale the system.

2.5.2. Interoperability

Layered designs encourage communication between various systems and parts. It is feasible to effortlessly combine components created by various teams or organizations by creating well-documented interfaces across levels. Modern technology ecosystems depend heavily on interoperability since it makes it possible to combine various systems.

2.5.3. Debugging and troubleshooting

It is easier to diagnose and troubleshoot problems when layers are isolated in a layered system. Developers don't have to be experts in every aspect of the system; instead, they may concentrate on a single layer to find and fix issues. This streamlines the debugging procedure and expedites the problem-solving process.

2.5.4. Reusability

Layered structures encourage the reuse of code. Components created for one system may frequently be reused in another, providing the interfaces between the levels are consistent, as each layer offers well-defined services and abstractions. This reusability shortens development cycles and eliminates the need to create anything from scratch.

2.6. Challenges and Things to Think About

Layered architectures provide many advantages, but there are also difficulties and things to take into account. When implementing layering concepts to a particular problem or domain, it is crucial to take these factors into account in order to make educated judgments.

2.6.1. Overhead

Overhead is introduced to some extent by layering. Each layer raises the level of abstraction and perhaps increases the computing expense. The trade-offs between abstraction and performance must be carefully considered in situations when performance is essential.

2.6.2. Being rigid

When the number of layers and the relationships between them are rigorously established, layered structures could display inflexibility. This lack of adaptability might, in some situations, make the system less able to keep up with new technologies or requirements.

2.6.3. Overengineering

A system may have been over-engineered if there were too many levels or abstractions. Overengineering can result in greater development costs, increased complexity, and worse system performance.

In summary, the concepts of abstraction, modularity, and hierarchical organization are the theoretical underpinnings of layered systems. These ideas have been used in a variety of fields, including networking, software engineering, and hardware design. Layering offers an organized method for handling complexity, fostering interoperability, and making system creation and upkeep easier.

We shall examine how these theoretical underpinnings appear in actual applications within the Theory of Digital (Layed) Technical Systems in the following chapters. To develop a thorough grasp of the role of layered architectures in influencing the digital landscape, we will delve into case studies, real-world examples, and current concerns. We hope to shed light on the transformational potential of layered systems and their ongoing applicability in the rapidly changing field of technology by linking theory and practice.

Chapter 3

Applications and Case Studies

In order to better understand how the case studies illustrate the core ideas of layered architecture, interdisciplinary cooperation, and the development of technical platforms in the context of digital innovation, we have gone further into the case studies from 3 different aspects, technical, design, and finally organizations. Each case study offers particular insights into these issues and exemplifies their importance across many fields.

The first group of articles demonstrates the value and adaptability of layered architecture in a variety of technical situations. The benefits of a layered design, the application of technology to improve system performance, and the importance of interdisciplinary collaboration in system design are all highlighted.

3.1. A Layered Architecture for Real-Time Systems.

The idea of layered architecture is crucial in the context of real-time systems when prompt and accurate answers are essential. With an emphasis on the modular and hierarchical approach to system design, this article provides a layered architecture customized to real-time systems. Each layer in this design has been given a distinct role, making it easier to handle complex systems.

Real-time systems' layered architecture adheres to the modular design ethos. This modularity makes development and debugging easier by allowing developers to concentrate on certain levels. Additionally, it makes it possible to seamlessly incorporate new additions or improvements without causing a systemic disruption.

High degrees of dependability and efficiency are required for real-time systems. The tiered method makes sure that real-time processing-essential processes are segregated and optimized inside certain levels. As a result, even in challenging circumstances, the system can maintain its performance and dependability.

3.2. An Open Architecture for Robot Entertainment

Innovators and creative people flourish in the realm of robot entertainment. As discussed in this paper, an open architecture emphasizes how crucial openness is for creating robot entertainment systems. This strategy promotes innovation and quick growth by encouraging various developers to contribute to the system.

Robot entertainment systems with open architectures encourage cooperation among programmers from various backgrounds. Teams with members with expertise in engineering, information technology, and the creative arts may use their combined skills to solve challenging problems and provide engaging user experiences.

3.3. Interactive Smart Classroom System Using Beacon Technology

Modern education has advanced technologically thanks to smart classrooms. In this article, beacon technology is used to provide an interactive learning environment that gives students real-time access to educational content.

Standard interfaces are crucial in the context of intelligent classroom systems. They provide smooth communication and cooperation between the system's many tiers and parts. Software developers may design programs that connect with the underlying hardware and improve the learning experience thanks to defined interfaces and protocols similar to those found in mobile phones.

3.4. An Example of an Evolving Modular Layered Architecture in Digital Innovation Is the Instrument Cluster in a Car

The automobile sector serves as an example of how layered architecture may change to accommodate new technologies. The instrument cluster of the car, an important part of contemporary cars, is the subject of this case study.

The layered architecture of the instrument cluster in a car must change as vehicles become more linked and software-reliant. It must support a variety of components and features, much to the idea of an interface in a mobile phone. To assure connection and compatibility across various levels and components and to make it easier to integrate new features and services, standards and protocols are essential.

3.5. Implementing Layered Modular Architecture in Digital Innovation: The Case of the Car's Driver Information Module

An additional level of sophistication in contemporary cars is represented by the driver information module. The success of a layered modular design in this situation is examined in this case study.

A better user experience is a result of the layered designs in driver information modules. They make it possible for cutting-edge amenities like navigation systems, driving assistance technology, and entertainment systems to be seamlessly integrated. With its several layers, this strategy keeps the system stable while providing drivers with useful information and capabilities.

3.6 Automated Driving in Real Traffic: Architectural Perspectives from Current Technical Approaches

Automated driving is a fundamental development in the field of transportation. The article looks at the use of layered architectures to improve the dependability and safety of autonomous driving systems.

The partitioning of functions into separate layers is a key tenet of layered architectures. This division enables the segregation of activities related to perception, decision-making, and management in the context of automated driving. Each layer adds to the system's overall effectiveness and safety.

3.7. Quantum Computing Layered Architecture

In the field of computing, quantum computing offers distinctive difficulties and potential. This case study examines how layered architecture offers a solid foundation for the creation and use of quantum computing techniques.

Stability and adaptability are guaranteed by layered systems in quantum computing. By offering a methodical way to handle the complexity of quantum systems, they make it possible to use quantum techniques for a variety of applications, ranging from cryptography to optimization issues.

Collectively, these case studies reveal several common themes and lessons. In a variety of fields, such as real-time systems, robot entertainment, smart classrooms, digital innovation, autonomous driving, and quantum computing, the idea of layered architecture is emerging as a unifying framework. A layered design has several benefits, including the potential to increase system efficiency, dependability, and flexibility, as well as its modularity and hierarchical structure.

Finally, cross-disciplinary cooperation and teamwork are essential elements in system design. These articles' writers come from a variety of academic fields, including engineering, information technology, physics, and the fine arts. Their collaborative approach exemplifies how different areas of knowledge may result in ground-breaking responses to difficult problems.

The dynamic environment of technology platforms has completely changed how companies work together, compete, and provide value. We are exploring Layered architecture from a design standpoint in the second section of our case study. Collectively, these papers provide light on how varied platform methods are, including topics like governance, openness, generative capability, and architectural design. Exploring these characteristics offers insightful information on how to manage platform ecosystems, encouraging innovation, participation, and value generation.

4.1. The Significance of Technological Platforms

The way firms conduct their operations has fundamentally changed thanks to technological platforms. These platforms offer a digital infrastructure that enables outside developers to produce services and goods that can be used by many people. The effects of this transition on collaboration, competitiveness, and value generation are significant.

Common characteristics of efficient platforms drive innovation and value development. They do this in two ways: first, by providing a standardized framework that enables builders to expand upon already-existing technologies and norms, quickening innovation and cutting costs of development. Second, they draw a large and diversified user base, which offers insightful feedback on fresh products. Thirdly, they make use of network effects, which increase the platform's value as additional users and developers sign up, fostering a positive feedback loop for development and innovation.

4.2. The Duality of Platform Governance

The success of a platform depends on efficient governance and management. Platform management frequently faces the difficulty of striking a balance between allowing access to other developers and preserving ownership of the platform. Several papers provided illumination on this precarious balance:

The crucial part platform governance plays in encouraging innovation while reducing risks is highlighted by Boudreau (2010). He separates the two main methods of platform governance into access-granting and control-delegating. While devolving power promotes openness and flexibility, granting access emphasizes control and consistency. According to Boudreau, effective platform governance calls for a careful balancing act between these two strategies that caters to the goals and circumstances of the platform.

Gawer (2014) presents a paradigm that unifies multiple platform views, such as organizational, technological, and strategic stances. She emphasizes the significance of understanding the complex relationships between these variables that influence platform dynamics. Gawer offers a collection of ideas and instruments for the research and administration of platform ecosystems, providing a more comprehensive comprehension of their governance.

In their 2013 study, Ghazawneh and Henfridsson explore how border resources help platform developers strike a compromise between control and transparency. They contend that in order to promote innovation, knowledge exchange, and the security of confidential information, platform owners must regulate the boundaries between internal and external players. For a platform to succeed, governance must be approached with sensitivity.

4.3. Generative Capacity: Fostering Innovation

The term "generative capacity" is used by Avital and Te'eni (2010) to describe an information system's capacity to support a range of complicated activities. Without generating ability, they argue, platforms cannot support innovation or value generation. In their set of design recommendations, Avital and Te'eni highlight the importance of generative capacity for fostering creativity and adaptation.

4.4. Architecture in Manufacturing Systems.

Axiomatic design theory is used by Delaram and Valilai (2016) to develop computer-integrated manufacturing systems. Their research emphasizes the value of adaptive architecture, component standardization, and modular design in promoting innovation and scalability. This case study illustrates how architectural concepts may be used in manufacturing.

4.5. Coordination and Adaptation

Platform design, governance, and environmental dynamics must be coordinated, according to the literature examined in these articles. To meet the variety and growth of user requirements and preferences, cooperation is crucial. It highlights how platform ecosystems are dynamic and adaptable to shifting market circumstances. As future Requirements, understanding the variables that affect platform success or failure is more important as platforms continue to play a significant role in many businesses and sectors. Platform governance, openness, and generative capability provide difficult challenges for managers, developers, and politicians. The ideas and techniques discussed in this literature lay a solid basis for managing platform ecosystems and open the door for more study and application of this field.

And lastly, a look at managing digital innovation, using knowledge from several influential papers. Together, the case examples in this part provide a paradigm that emphasizes the many facets of managing digital innovation. They explore the traits, conceptualizations, organizational logic, and management strategies of digital innovation, illuminating its profound influence on both enterprises and society.

5.1. Digital Innovation: Definitions and Characteristics

The theoretical and practical aspects of digital innovation are emphasized in all the essays in this collection. They examine the distinctive qualities of digital artifacts and the conceptualization of these advances within organizations. This investigation emphasizes the complex interaction between organizational culture and technology.

"The Quest for New Theoretical Logics of Digital Innovation" explores the connection between the characteristics of digital artifacts and how they are conceptualized within organizations. It makes the case that new theoretical frameworks are necessary to fully understand the social and cultural dynamics of digital innovation. The necessity to close the gap between technology characteristics and organizational perceptions is highlighted by this viewpoint.

5.2. The Dual Regimes of Digital Innovation Management

Collectively, the pieces recognize how a paradigm change in corporate operations and competition has been brought about by digital innovation. Digital technologies have fueled the growth of new technological system layers, which have changed how people interact with goods, services, and the larger market.

The idea of multi-layered technical systems serves as an excellent example of this change. Consider the physical layer, which a smartphone serves as an example. It serves as a platform for other players to enter the market and increase the usability of the device through software apps. This multi-layered technical structure serves as an example of how digital innovation has created new opportunities for commerce and creativity.

The books "Organising for Innovation in the Digitised World" and "The New Organising Logic of Digital Innovation" explore the difficulties conventional hierarchical organizations confront in adjusting to the quick-moving and diffuse nature of digital innovation. They contend that traditional methods of innovation management are ineffective in a setting where digital platforms and ecosystems are the primary drivers of innovation.

The paper titled "DIGITAL INNOVATION MANAGEMENT: REINVENTING INNOVATION MANAGEMENT RESEARCH IN A DIGITAL WORLD" argues that managing digital innovation has to change. It argues that in the digital age, conventional approaches to innovation management are ineffective. It suggests a new paradigm in its place that takes into consideration the unique aspects of digital innovation, such as open innovation, user involvement, and platform-based ecosystems.

5.3. Beyond Technology: Societal Implications

The papers also acknowledge that digital innovation has accompanying societal changes in addition to technological improvements. The effects of digital innovation go beyond the realm of technology and affect how people, groups, and communities interact and develop.

These pieces emphasize the need to use a multidisciplinary approach while researching and utilizing digital innovation. This is demonstrated in "The Quest for New Theoretical Logics of Digital Innovation" by highlights the significance of new theoretical logic to understanding the social and cultural dynamics of digital innovation. Collaboration across technological, organizational, and social viewpoints is necessary to comprehend the wider societal ramifications of digital innovation.

All in all, the incorporation of common frameworks into architectural design is essential in the quickly changing technology world of today. Layering improves the flexibility and scalability of the system, open design encourages collaboration and creativity, and a balance between control and contribution assures excellence and innovation. Value is increased by aligning with corporate goals and user experience, and innovation management promotes ongoing development.

Organizations may develop platforms and systems that are not only technically sound but also adaptable, user-centric, and ready for long-term innovation by using these principles across a variety of architectural settings, from real-time systems to digital innovation. These principles provide as a road map for navigating the difficulties of contemporary architectural design and dealing with the effects of the digital economy.

Chapter 4

Proposals and a Real-World application

In the upcoming chapter, we will examine how smart mirrors—a powerful real-world illustration of how layered architecture may revolutionize ordinary experiences—apply digital layered technological systems.

Smart Mirrors

4.1. Smart Mirror

Designing and creating a smart mirror is one illustration of how common themes among our case studies can be used. The design of the system can be divided into levels using layering, each with its own set of tasks and interactions with other layers.
Innovative mirrors known as "Smart Mirrors" include technology to perform several other functions besides serving as a mirror, such as showing weather information, playing music, and keeping track of health parameters. I'll outline the layers of the Smart Mirrors design, present justifications for my choices, and suggest alternate approaches.

Layer 1: Hardware Layer

The Hardware Layer, which contains all the actual parts of the mirror, is the top layer in the architecture of Smart Mirrors. This also applies to the mirror itself, which might be a standard mirror or a unique kind of mirror with technology built in. A display screen, sensors for data collection (such as temperature, humidity, and motion), a CPU for data processing, networking components (such as Wi-Fi and Bluetooth), and a power source (such as batteries or a power outlet) are examples of additional hardware elements.

The purpose of including these parts is to allow the Smart Mirror's fundamental features, such as information display and data collection from the surroundings.

Different kinds of mirrors, such as OLED mirrors, which offer superior visibility and picture clarity compared to conventional mirrors, might be used as alternatives to the Hardware Layer. Based on particular use cases and specifications, different connectivity solutions like Zigbee or NFC can also be taken into consideration. The Smart Mirror's unique functionality and performance needs will determine the sensors and microprocessors that are used.

<u>Layer 2: Software Layer</u>

The software layer, which comprises the operating system, middleware, and applications that run on the mirror, is the second layer in the architecture of Smart Mirrors. The operating system offers the core software necessary to control hardware resources, handle interfacing with other systems or services, and offer security measures. Providing features like data synchronization, device connection, and application programming interfaces (APIs) for developers to construct applications, middleware serves as a link between the operating system and the applications. Applications are user-facing programs that offer the Smart Mirror's features, such as showing weather data, playing music, and keeping track of health measures.

These software components are included because they will allow the Smart Mirror to run various programs and offer a user-friendly interface for interacting with the mirror. Depending on the needs of the Smart Mirror, alternative operating systems, middleware, or application frameworks may be used as the Software Layer. To improve security or performance, for instance, a specialized operating system or middleware may be created. The Smart Mirror's capabilities may also be expanded through the integration or development of third-party apps or widgets.

Layer 3: Data Layer

The Data tier, which is the third tier in the architecture of Smart Mirrors, contains the data that the mirror captures, processes, and stores. Data from sensors, user interactions, and other sources, like weather APIs or health monitoring services, are all included in this. For additional processing and analysis, the data may be handled locally on the mirror or sent to external servers. The processed data can be utilized to provide insights, personalize suggestions, or show information on the mirror.

The Data Layer is included to allow the Smart Mirror to collect and interpret environmental data and deliver pertinent information to the user.

Depending on the specific functionality of the Smart Mirror, alternative options for the Data Layer may involve using various kinds of sensors or data sources. For voice control or facial recognition, additional sensors like a camera or microphone could be used. Depending on the needs of the Smart Mirror, other data storage and processing technologies, including cloud storage or edge computing, may also be taken into consideration.

Layer 4: User Experience Layer

The entire process of utilizing the Smart Mirror is covered by the user experience layer. This covers the device's functioning and user-friendliness, as well as the style and structure of the user interface. In order to create a product that customers will find appealing and simple to use, the user experience layer is essential.

I'll use the **organizational implications framework** that is common to several academic papers, on "Smart Mirrors" here. This concept relates to the effects that smart mirror adoption has on the businesses engaged in their design, manufacture, and distribution.

The necessity of cross-functional collaboration across many corporate departments and functions is one of the major organizational consequences of smart mirrors. Hardware, software, and data analytics are all combined in smart mirrors, therefore product design, engineering, data science, and marketing knowledge are all needed. To guarantee that all components of the product development process are in alignment and that there is good communication between various departments, businesses must establish cross-functional teams.

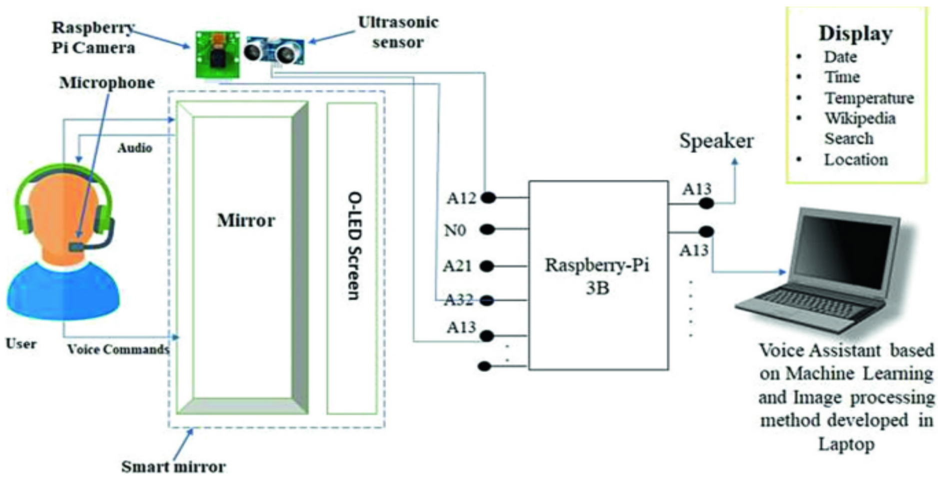
The requirement for organizations to embrace an agile development method is another organizational impact of smart mirrors. A lot of complexity and unpredictability go into smart mirrors, and new features and technologies are always being developed. Companies need to embrace an agile development methodology that enables them to swiftly test and iterate on new ideas while also guaranteeing that the product is delivered on time and under budget if they are to stay up with the speed of innovation.

A shift in corporate culture is also necessary for the adoption of smart mirrors. Companies must promote an innovative and experimental culture where workers are encouraged to take chances and test out novel concepts. In order to do this, old hierarchical structures must give way to a more decentralized and collaborative strategy.

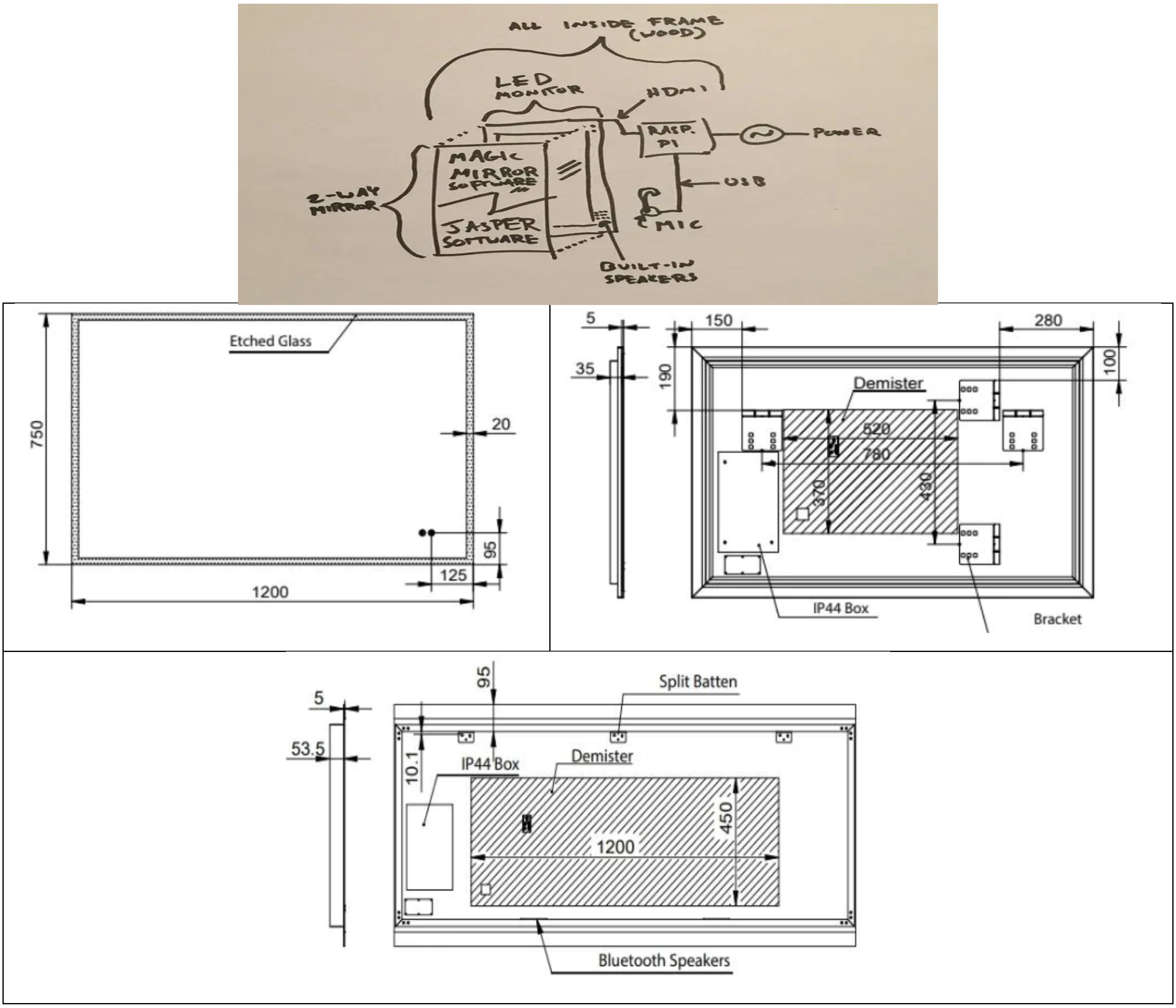
The requirement for organizations to have a strong data management system is another significant organizational impact of smart mirrors. A lot of data is produced by smart mirrors, including user preferences, usage trends, and purchase behaviors. Companies require a data management system that can gather, store, analyse, and meaningfully visualize data if they are to make use of this data.

The deployment of smart mirrors also forces businesses to reconsider their sales and distribution strategies. When compared to traditional retail channels, smart mirrors are frequently offered through online or in-store kiosks, necessitating a distinct strategy for distribution and marketing. Businesses must make investments in innovative marketing and distribution plans that consider the special qualities and advantages of smart mirrors.

In conclusion, organizations must consider the organizational implications of smart mirrors when designing and introducing these devices. Companies must promote an innovative culture, use an agile development approach, and invest in cross-functional teams, data management systems, and new distribution and sales channels to ensure the success of smart mirrors.



4.2. Smart Mirror (Block Diagram)



4.3. Smart Mirror(layers)

"Smart Mirrors." This is an outstanding illustration of the real-world use of digital (layered) technical systems These mirrors combine many technological layers to offer cutting-edge features, from customized grooming help to interactive information display. Considering the common frameworks and ideas addressed in the earlier texts, the following suggestions are made in the domain of smart mirrors:

Individualized grooming support:

Layering: Use a tiered architecture to divide tasks like facial recognition, skin analysis, and virtual cosmetics applications within the Smart Mirror. Each layer works together to offer suggestions and help for individual grooming.

Open Design: Permit customers to personalize and include skincare and cosmetics in the Smart Mirror's suggested purchases. Collaboration with beauty businesses for cooperation and product suggestions is encouraged by open design.

Maintaining Control While Allowing External Contributors, such as Beauty Experts or Influencers, to Offer Input on Recommended Products and Techniques: Maintain Control Over the Accuracy and Safety of Product Recommendations.

User Experience: To provide a first-rate user experience, prioritize an intuitive user interface with touch or voice commands. Adapt the design to user choices and make skincare and cosmetic tutorials easily accessible.

Management of Innovation: Update the Smart Mirror's algorithms frequently to reflect the newest developments in skincare and cosmetics. To promote innovation in grooming assistance, work with research institutes and beauty professionals.

Fitness tracking and health:

Layering: Design a multi-sensor health monitoring system that includes sensors for measuring heart rate, body composition, and activity. Real-time health insights are provided by the interaction of these levels.

Open Design: Allow users to easily incorporate their exercise routines, dietary information, and health objectives into the Smart Mirror's user interface by opening the platform to third-party health and fitness apps.

Maintaining a Balance Between Control and Contribution: Maintain data security and privacy while enabling outside fitness specialists to share workout regimens, nutrition suggestions, and health advice. Implement stringent data access control measures.

Design the Smart Mirror's user interface to deliver customized training plans, track results, and provide health suggestions depending on user objectives. Emphasize developing a user experience that is inspiring and interesting.

To keep current on the newest trends in health and fitness, collaborate with healthcare professionals and fitness gurus. Update the system often to include new workout routines, nutrition recommendations, and health techniques.

Integration of retail and fashion:

Layering: Create an architecture with layers that blend e-commerce, augmented reality (AR), and image recognition. The Smart Mirror allows users to digitally try on apparel and accessories.

4.4. Smart Mirror (retail and fashion)

Open Design: Work with merchants and fashion companies to incorporate their product catalogs into the Smart Mirror. Permit consumers to browse and buy clothes and accessories right from the mirror.

Maintaining Control Over Accuracy of Virtual Try-On Technology While Enabling Fashion Influencers and Stylists to Curate and Recommend Outfits: Balance Control and Contribution.

User Experience: Give people a smooth and immersive shopping experience that allows them to virtually try on clothing, get styling advice, and make purchases without ever leaving their homes.

Innovation management: Keep up with the latest fashions and add the newest collections to the Smart Mirror's selection. Join forces with designers and industry professionals to provide unique style advice.

To develop cutting-edge and user-focused Smart Mirror apps, these suggestions make use of the common frameworks of layering, open design, balancing control and contribution, alignment with user experience and business objectives, and innovation management. They ensure that these real-world implementations of Digital (Layered) Technical Systems offer users value, flexibility, and continual innovation since they are in line with the ideas covered in the earlier publications.

Chapter 5

Conclusion

In this final chapter, we will first investigate future proposals and directions for advancements in Digital (Layered) Technical Systems. Given the evolving nature of technology and its applications, here are some forward-looking research proposals that can contribute to the advancement of this field. In the journey of digital(layered) technical systems, there are a lot of areas for exploration and further research we would recommend that can shape the future of this field:

1. Layered Cybersecurity for IoT Ecosystems:

   Proposal: Create a thorough, multi-layered cybersecurity framework that is especially suited for Internet of Things (IoT) ecosystems. This architecture should include separate levels for user access control, device security, network security, and data security. To build a strong defense against IoT-related attacks, each layer should communicate with one another without any gaps.

   Objective: Addressing the rising concern over cyberattacks in smart homes, smart cities, and industrial IoT, improve the security and privacy of IoT devices and networks.

2. Smart Healthcare Integration:

   Proposal: Create an integrated, layered system for applications in smart healthcare. This system should have layers for managing healthcare facilities, analyzing medical data, and monitoring patients. In order to enable real-time health monitoring and proactive healthcare delivery, place a strong emphasis on interoperability and secure data exchange between layers.

   Objective: Revolutionize the healthcare sector by making continuous remote patient monitoring possible, raising the accuracy of diagnoses, and maximizing the use of available resources.

3. Autonomous Transportation and Urban Mobility:

   Proposal: Create a multi-layered system for urban mobility and autonomous vehicles. The layers should include infrastructure coordination, traffic management, passenger experience, and autonomous vehicle control. Use cutting-edge machine learning and artificial intelligence (AI) technologies to make decisions inside the system more effectively.

   Objective: Improve safety, traffic flow, and urban mobility while accelerating the transition to autonomous transportation systems.

4. AI with Layers for Customized Learning:

   Proposal: Create a multi-layered artificial intelligence system for individualized instruction. Create layers for performance metrics, content recommendations, teacher support, and student evaluation. Utilize adaptive learning algorithms to customize students' educational experiences.

   Objective: Transform the educational landscape by offering personalized learning pathways that consider each student's particular requirements and rate of learning.

5. Management of energy in smart grids:

   Proposal: Making a multilayer smart grid energy management system is the suggestion. Grid monitoring, demand forecasting, energy delivery, and consumer control should all be covered by layers. Utilize edge computing and real-time data analytics to maximize energy efficiency and minimize waste.

Objective: Boost energy system resilience in response to shifting energy needs and the incorporation of renewable energy sources. Improve energy efficiency.

These ideas reflect intriguing new prospects for Digital (Layered) Technical Systems, where layering techniques may be used to address difficult problems and spur innovation in a variety of fields, including cybersecurity, healthcare, and other areas. Their emphasis on layering, open design, control and contribution balance, user experience, and innovation management is consistent with the common frameworks previously addressed.

Conclusion

Through a variety of scholarly publications and conversations, the study of Digital (Layered) Technical Systems has given researchers insightful knowledge about this developing area. The overall themes of layering, open design, control and contribution balance, user experience, and innovation management have been regularly seen in a variety of applications, from smart mirrors to healthcare, banking, transportation, and beyond. These ideas highlight the value of organized and adaptable architectures in tackling difficult technical problems and maximizing the promise of digital innovation.

Layering has become a key concept in providing flexibility, scalability, and organization, as demonstrated by the architectural designs of many systems. The creation of complete cybersecurity frameworks for IoT ecosystems or the use of smart mirrors for personalized grooming help, layering offers a modular and hierarchical approach that improves system performance.

Open design, a crucial element of many of the apps put out, encourages innovation, collaboration, and interoperability. It encourages active engagement with systems from users, developers, and outside contributors, stimulating innovation and speeding growth. The open design supports product development in the age of digital innovation and matches changing customer preferences and corporate goals.

The necessity to maintain some level of control to assure uniformity, quality, and security while embracing outside contributions and innovation has been a recurring subject. The coexistence of external contributors and internal control systems is essential in platform strategies because it fosters innovation and preserves platform integrity.

The significance of user experience is highlighted by the focus on it across a variety of applications, including smart mirrors, healthcare systems, and educational platforms. The effectiveness of digital systems is ultimately influenced by user-centric design, which not only improves usability but also encourages user pleasure and adoption.

In the context of digital innovation, in particular, innovation management has been a major challenge. Researchers and practitioners have drawn attention to the need for novel solutions to the problems the digital economy has brought about. This entails adjusting to new organizing logic, investigating dual innovation management systems, and creating cutting-edge theoretical frameworks that consider the constantly changing digital innovation ecosystem.

The study of Digital (Layered) Technical Systems reveals a dynamic and multidimensional subject where recurrent themes and guiding principles drive innovation across a range of applications. Researchers, engineers, and designers are given the ability to influence the direction of technology through the integration of layers, open design, control and contribution balance, user experience, and innovation management. These principles guarantee that systems are in line with user demands, company objectives, and developing trends in the digital economy, in addition to improving the adaptability and scalability of such systems. It is essential to take these ideas into account as we traverse the quickly changing technological world to create and manage complex systems that enhance our quality of life, encourage creativity, and promote ongoing innovation.

REFERENCES

1. A layered architecture for real-time systems, Satyanarayana, N V and Mall, R and Pal, A (1996) A layered architecture for real-time systems. Microprocessors and Microsystems, 20 (4). pp. 241-250. &

2. An open architecture for Robot Entertainment Masahiro Fujita and Koji Kageyama D21 Laboratory, Sony Corporation 6-7-35, Kitashinagawa Shinagawa-ku, Tokyo, 141 Japan mfujita@pdp.crl.sony.co.jp, kage@pdp.crl.sony.co.jp.

3. Interactive smart classroom system using beacon technology Hu Jia Dong1, Raed Abdulla2, Sathish Kumar Selvaperumal3, Shankar Duraikannan4, Ravi Lakshmanan5, Maythem K. Abbas6 1-5School of Engineering, Asia Pacific University of Technology and Innovation (APU), Technology Park Malaysia, Malaysia 6Faculty of Science and Information Technology, Universiti Teknologi PETRONAS, Malaysia.

4. EVOLVING THE MODULAR LAYERED ARCHITECTURE IN DIGITAL INNOVATION: THE CASE OF THE CAR’S INSTRUMENT CLUSTER Conference Paper · January 2013.

5. Accomplishing the layered modular architecture in digital innovation: The case of the car’s driver information module Lena Hylvinga,∗, Ulrike Schultze a School of Information Technology, Halmstad University, Kristian IV:s väg 3, 301 18 Halmstad, Sweden ITOM, Cox School of Business, Southern Methodist University, PO Box 750333, Dallas, TX 75275-0333, United States.

6. Automated Driving in Real Traffic: from Current Technical Approaches towards Architectural Perspectives CITATION: Hohm, A., Lotz, F., Fochler, O., Lueke, S. et al., "Automated Driving in Real Traffic: from Current Technical Approaches towards Architectural Perspectives," SAE Technical Paper 2014-01-0159, 2014, doi:10.4271/2014-01-0159.
7. Layered Architecture for Quantum Computing N. Cody Jones,1,* Rodney Van Meter,2 Austin G. Fowler,3 Peter L. McMahon,1 Jungsang Kim,4 Thaddeus D. Ladd,1,5 and Yoshihisa Yamamoto1,5.
8)Open Platform Strategies and Innovation: Granting Access vs. Devolving Control Kevin Boudreau Department of Strategy and International Management, London Business School, London NW1 4SA, United Kingdom.

9. "Bridging differing perspectives on technological platforms: Toward an integrative framework" Annabelle Gawer and published in the journal "Business & Research Policy" on September 1, 2014.

10. Balancing platform control and external contribution in third-party development the boundary resources modelisj_406 1Ahmad Ghazawneh* & Ola Henfridsson†.

11. Research Commentary —Platform Evolution: Coevolution of Platform Architecture, Governance, and Environmental Dynamics Article in Information Systems Research · December 2010.

12. From generative fit to generative capacity: exploring an emerging dimension of information systems design and task performance
Michel Avital* & Dov Te'eni† *the University of Amsterdam, Amsterdam, The Netherlands, email: avital@uva.nl, and †Tel Aviv University, Tel Aviv, Israel.

13. An architectural view to computer integrated manufacturing systems based on Axiomatic Design Theory
Jalal Delaram, Omid Fatahi Valilai*
Advanced Manufacturing Laboratory, Department of Industrial Engineering, Sharif University of Technology, Tehran, Iran.

14. The Quest for New Theoretical Logics of Digital Innovation: Linking Properties of Digital Artifacts with their Conceptualizations in Organizations Date:2021-01-05 Authors: Hron, Michal.

15. The Dual Regimes of Digital Innovation Management
F. Svahn, O. Henfridsson Published 4 January 2012
Business 2012 45th Hawaii International Conference on System Sciences.
16. The New Organizing Logic of Digital Innovation: An Agenda for Information Systems Research
Youngjin Yoo, Center for Design and Innovation, Temple University, Philadelphia, Pennsylvania 19122, yxy23yoo@gmail.com
Ola Henfridsson, Viktoria Institute Hörselgängen 4, 41756 Göteborg, Sweden, and Department of Informatics, University of Oslo, N-0316 Oslo, Norway, ola.henfridsson@viktoria.se
Kalle Lyytinen, Department of Information Systems, Case Western Reserve University, Cleveland, Ohio 44106, kjl13@case.edu.

17. Organizing for Innovation in the Digitized World
Youngjin Yoo Fox School of Business, Temple University, Philadelphia, Pennsylvania 19122, youngjin.yoo@temple.edu Richard J. Boland Jr., Kalle Lyytinen Weatherhead School of Management, Case Western Reserve University, Cleveland, Ohio 44106 {boland@case.edu, kalle@case.edu} Ann Majchrzak Marshall School of Business, University of Southern California, Los Angeles, California 90089.

18. DIGITAL INNOVATION MANAGEMENT: REINVENTING INNOVATION MANAGEMENT RESEARCH IN A DIGITAL WORLD
Satish Nambisan _Lubar School of Business, University of Wisconsin–Milwaukee, 3202 N. Maryland Avenue, Milwaukee, WI 53211 U.S.A. {nambisan@uwm.edu}
Kalle Lyytinen_Weatherhead School of Management, Case Western Reserve University, 10900 Euclid Avenue, Cleveland, OH 44106 U.S.A. {kjl13@case.edu}
Ann Majchrzak _Marshall School of Business, University of Southern California, Los Angeles, CA 90089 U.S.A. {majchrza@usc.edu}
Michael Song _School of Economics and Management, Xi'an Technological University, Weifang District, Xi'an City CHINA

19. "Smart Mirrors: A Review of the State-of-the-Art" **Authors:** Mohamed Mostafa, Georgi N. Gaydadjiev. IEEE Internet of Things Journal, 2020

20. **Reference Title:** "Smart Mirror as an Emerging Application on the Internet of Things"
Hadi Arampis, Drakoulis Martakos. Proceedings of the 2018 IEEE International Conference on Industrial Internet, 2018

21. **Reference Title:** "An Experimental Study on Virtual Dressing Room with a Smart Mirror"
Ayoub Benslimane, Wassim Hamidouche, et al. Proceedings of the 2015 International Conference on Image Processing Theory, Tools, and Applications (IPTA), 2015

22. "Layering as a Structuring Principle for Innovation Research"
Nikolaus Franke, Christopher Lettl
International Journal of Innovation Management, 2010

23. "Innovating for Sustainability: A Framework for Sustainable Innovations and a Model of Sustainable Innovations in Practice"
Nuno F. da Cruz, Jorge C. Alves, Ana H. A. B. Duarte
Innovation: Management, Policy & Practice, 2010

24. "The Interactive Mirror: A Case Study" Federico Barrera, Iván Sipiran
Proceedings of the 2017 ACM International Conference on Interactive Surfaces and Spaces, 2017