5G HYPER-CONNECTED UNIVERSITY CAMPUS: ENHANCING THE EDUCATION EXPERIENCE

Lappeenranta–Lahti University of Technology LUT

Master’s Program of Global Management of Innovation and Technology, Master’s thesis 2024

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Examiners: Professor Leonind Chechurin PhD.

Thomas Hainzel, M.Sc.
Abstract

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Keywords: 5G, technology, university campus, smart campus, higher education, digital transformation, 5G use cases, enhanced education, innovation, industry 4.0, partnership.

The rapid advancement of technology, coupled with the emergence of fifth-generation telecommunication (5G), has prompted various industries to rethink their approach to digitalization and automation. However, the impact of 5G technology on the education sector, particularly within university campuses, remains underexplored. This study investigates how a 5G hyperconnected campus can enhance the educational experience and better prepare students for Industry 4.0.

Through a systematic literature review and empirical data collection, the research highlights how 5G technology can enhance learning environments, improve experiential learning, overcome traditional Wi-Fi limitations, and enhance collaboration and innovation. It also identifies challenges such as funding complexities, technical difficulties, and lack of 5G awareness among stakeholders. Based on these findings, a conceptual model is proposed to transform traditional Wi-Fi-enabled campuses into dynamic 5G hyperconnected spaces.

This research provides evidence of successful 5G integration within university campuses and develops a framework showcasing the value realization through strategic 5G adoption. The study offers a roadmap for future implementation and collaboration between academia, government, and industry emphasizing the potential of 5G to revolutionize educational environments and drive economic and sustainable growth.
Acknowledgments

It's hard to believe that my master’s project, which started as a mere idea, is now coming to an end. This journey has been incredibly enriching, allowing me to meet amazing people who expanded my horizons, challenged me, and generously shared their experiences. The program also granted me the incredible opportunity to study in South Korea, an experience I will always cherish and be grateful to LUT University and Sungkyunkwan University.

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I extend my sincere thanks to the university professors, administrative staff, students, and Nokia colleagues who participated in the interviews and supported me by completing the thesis survey. Special thanks to Tampere University, Oulu University, Tampere Applied Science University, Savonia Applied Science University, and Lapland Applied Science University for hosting me and demonstrating their 5G test bed programs and forward-thinking projects.

Additionally, I am profoundly grateful to my parents Ariel and Aura for instilling the value of education and encouraging me to pursue my goals. My fiancé Nicholas, your unwavering support has meant the world to me. To my nephew Santiago, who provided the strength and encouragement I needed during challenging moments, and to my friends who continually motivated me—thank you.

Looking to the future with excitement, I imagine a medical student testing robotic surgery, a civil engineering student remotely controlling excavation equipment, and an industrial engineering student mastering autonomous production lines. This thesis is a step toward realizing that vision, and I am eager to see its impact unfold.
<table>
<thead>
<tr>
<th>Symbol</th>
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<tbody>
<tr>
<td>1G</td>
<td>First-Generation</td>
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<td>2G</td>
<td>Second-Generation</td>
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<td>3D</td>
<td>Three dimensions</td>
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<td>3G</td>
<td>Third-Generation</td>
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<td>4G</td>
<td>Fourth-Generation</td>
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<td>4IR</td>
<td>Fourth Industrial Revolution</td>
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<td>5G</td>
<td>Fifth-Generation</td>
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<td>5GIC</td>
<td>5G Innovation Centre</td>
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<td>5GTNF</td>
<td>5G Test Network Finland</td>
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<td>6G</td>
<td>Sixth-Generation</td>
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<tr>
<td>AI</td>
<td>Artificial Intelligence</td>
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<td>AR</td>
<td>Augmented Reality</td>
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<td>ATG</td>
<td>Advanced Technologies Group</td>
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<td>CMU</td>
<td>Carnegie Mellon University</td>
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<td>CO2</td>
<td>Carbon Dioxide</td>
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<tr>
<td>eMBB</td>
<td>Enhanced Mobile Broadband</td>
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<tr>
<td>FlexE</td>
<td>System Flexibility</td>
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<tr>
<td>GHz</td>
<td>Gigahertz</td>
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<tr>
<td>HVAC</td>
<td>Heating Ventilation and Air Conditioning</td>
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<tr>
<td>ICT</td>
<td>Information Communications Technology</td>
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<tr>
<td>ICTE</td>
<td>Information Communication and Technology in Education</td>
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<tr>
<td>IEEE</td>
<td>Institute of Electrical and Electronics Engineers</td>
</tr>
<tr>
<td>IIoT</td>
<td>Industrial Internet of Things</td>
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<tr>
<td>IoT</td>
<td>Internet of Things</td>
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<td>IT</td>
<td>Information Technology</td>
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<tr>
<td>LMS</td>
<td>Learning Management Systems</td>
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<td>LUT</td>
<td>Lappeenranta-Lahti University of Technology</td>
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<tr>
<td>Mbps</td>
<td>Megabits Per Second</td>
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<td>MCS</td>
<td>Mission Critical Services</td>
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<td>MIMO</td>
<td>Multiple Input, Multiple Output</td>
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<tr>
<td>mIoT</td>
<td>Massive Internet of Things</td>
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<tr>
<td>Acronym</td>
<td>Description</td>
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<tr>
<td>ML</td>
<td>Machine Learning</td>
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<td>OER</td>
<td>Open Educational Resources</td>
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<td>PhD</td>
<td>Doctor of Philosophy</td>
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<td>R&amp;D</td>
<td>Research and Development</td>
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<tr>
<td>SGEMM</td>
<td>Smart Grids and Energy Markets</td>
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<tr>
<td>SLR</td>
<td>Systematic literature review</td>
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<tr>
<td>SMS</td>
<td>Short Message Service</td>
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<tr>
<td>TAMK</td>
<td>Tampere University of Applied Science</td>
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<tr>
<td>UNESCO</td>
<td>United Nations Educational, Scientific and Cultural Organization</td>
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<tr>
<td>VR</td>
<td>Virtual Reality</td>
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<tr>
<td>WiFi</td>
<td>Wireless Fidelity</td>
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<tr>
<td>WWW</td>
<td>World Wide Web</td>
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1 Introduction

The journey from 1G to 5G has been a thrilling transformation, evolving mobile communication from basic voice calls to a powerful ecosystem of connectivity and innovation (Moore 2023). Universities, as epicenters of knowledge and innovation, stand to benefit immensely from this technological leap. The continuous expansion of university campuses and the significant transformation in the digital era have reshaped the way students learn, teachers teach, and researchers collaborate (Wessels and Van Wyk 2022). One of the most promising and disruptive technologies to enable this transformation is 5G, the fifth generation of mobile communication networks.

Despite the introduction of 5G in the early 2000s, its adoption within the education sector has been slow, and there remains a limited amount of research and knowledge on the subject. Most existing literature comes from telecommunication vendors, analysts, and consultancy companies, but there is a lack of deep, academic research on the topic. Previous studies have demonstrated the potential benefits of digital technologies in education, but they often fail to comprehensively address the specific impacts and practical applications of 5G within the university setting. This gap highlights the necessity for focused research on how 5G can specifically enhance learning environments, facilitate experiential learning, integrate advanced technologies across faculties, and prepare students for the demands of Industry 4.0.

This paper aims to identify the benefits that the integration of 5G technology can bring to university campuses, highlighting the use cases and partnerships required to leverage this technology effectively. The research question guiding this study is: "How does a 5G hyper-connected campus enhance the education experience?" The paper is structured into three main parts: the introduction, the study (comprising literature review, methodology, and findings), and the conclusion with future research directions. The goal is to summarize the various benefits that 5G can bring to university campuses, visualize the 5G-enabled use cases through a conceptual model, and highlight the collaboration framework needed to leverage 5G in the university environment. Additionally, this document will identify the challenges and concerns associated with 5G implementation and propose managerial recommendations.
1.1 Background of the Study

For centuries, higher education has undergone significant evolution, transitioning from the medieval emphasis on scholasticism and the classical focus on humanism to the modern era characterized by scientific inquiry, and more recently, to the postmodern era marked by interdisciplinary approaches and societal engagement with science and technology (Moore 2023). Illustrated in the figure below are the three pivotal ages and the seven fundamental pillars that underpin the foundation and progression of universities, highlighting 5G in the context of the university campus as the core topic of this study.

![University Foundations and Evolution](image)

Figure 1. University foundations and evolution.

A detailed explanation of Figure 1 will be provided in the introductory section of the literature review chapter, which is dedicated to a deep dive into the foundational aspects and evolutionary trajectory of universities.

The advent of the digital age has brought new opportunities and challenges for higher education, as new technologies and pedagogies are transforming the modes, methods, and outcomes of learning, teaching, and research. Some of the key drivers of this transformation are shown in the following figure and consequently explained in more detail (Derrick et al. 2016).
1. The increasing demand for higher education and lifelong learning, as the knowledge economy and the global society, require more skilled and adaptable workers and citizens (Derrick et al. 2016).

2. The diversification of learners and learning needs, as the student population becomes more heterogeneous in terms of age, background, culture, preferences, and abilities (Derrick et al. 2016).

3. The expansion of learning resources and environments, as the internet and digital media provide access to a vast amount of information and content, as well as to various online and blended learning platforms and communities (Derrick et al. 2016).

4. The innovation of learning design and assessment, as the digital tools and data enable more personalized, adaptive, collaborative, and authentic learning experiences and outcomes (Derrick et al. 2016).

5. The development of learning science and analytics, as interdisciplinary research and big data provide new insights and evidence into the cognitive, affective, and social aspects of learning and teaching (Derrick et al. 2016).

University 4.0 is a new concept in the teaching and learning area that proposes to prepare students and the new generations of learners for the upcoming industrial revolution which requires new skills and includes new technologies such as advanced robotics, Industrial Internet of Things (IIoT), 3D printing and wireless technology like the fifth generation. 5G is a pivotal technology capable of facilitating and accelerating the digital evolution of university education, by providing the following advantages (Kizilkaya et al. 2021):
- **High speed and capacity**: 5G can provide up to 100 times faster data rates and 1000 times more capacity than 4G, allowing for seamless and high-quality transmission of large and complex data, such as video, audio, and virtual reality (VR) (Kizilkaya et al. 2021).

- **Low latency and reliability**: 5G can reduce the delay in data transmission to less than 1 millisecond and ensure 99.999% reliability, enabling real-time and interactive communication and feedback, as well as critical and emergency applications, such as remote surgery and autonomous vehicles (Kizilkaya et al. 2021).

- **Massive connectivity and scalability**: 5G can support up to 1 million devices per square kilometer, creating a hyper-connected environment that can integrate various devices and sensors, such as smartphones, tablets, laptops, wearables, cameras, drones, robots, and internet of things (IoT) (Kizilkaya et al. 2021).

- **Energy efficiency and sustainability**: 5G can reduce the energy consumption and the carbon footprint of the network by up to 90%, contributing to the environmental and social responsibility of the education sector (Kizilkaya et al. 2021).

As universities keep re-shaping and rethinking the future network architecture that meets future digital requirements, higher education must carefully evaluate which technologies are most appropriate to support their planned use cases and services. To fully capitalize on Industry 4.0 and the smart IoT evolution, universities should select technologies that are also...
being adopted by fellow academic institutions and industry collaborators for digital transformation (Sabourin 2021).

1.2 Research Objectives and Questions

The thesis research aims to expand upon existing literature by examining the impact of 5G technology on university campuses. This involves assessing the benefits facilitated by 5G, exploring the use cases enabled by this technology, and understanding the collaborative partner ecosystem necessary to leverage its full potential.

The key research objectives are outlined as follows:

- To offer an understanding of the benefits that 5G technology brings to different stakeholders within the university environment.

- To identify a diverse array of use cases that can be developed using 5G technology within university campuses.

- To gain insights from universities already implementing 5G technology through the 5G Test Network Finland initiative enabled by Nokia’s technology.

- To comprehend the partnership ecosystem essential for the efficient deployment and utilization of advanced wireless communication technology in universities.

To align with these objectives, the central research question has been formulated as follows:

1. How does 5G hyper-connected university campus enhance the education experience?

The main research question is complemented by three sub-questions, which help to clarify and extend the reach of the main research question:

- What are the 5G-enabled use cases and case studies on the university campus?

- What are universities’ references to 5G technology, use cases developed, and partner ecosystem engaged?
1.3 Scope of the Study

This study focused on exploring the benefits of 5G technology within the university campus environment. This narrowing of the scope enables a more comprehensive and detailed analysis, both theoretically and empirically, within this educational context.

The education sector is indeed broad and complex, with numerous organizations, stakeholders, and levels of operation. To manage this complexity and narrow the scope, the study focuses exclusively on the university campus environment. This concentration allows for a more in-depth analysis of a specific segment within the broader education sector.

1.4 Structure of the Thesis

Five sections are structured for the development of the thesis, as presented in Figure 4. The introduction offers an overarching view of the research, outlining its background, objectives, and questions. Subsequently, the literature review delves into recent scholarship surrounding the history and evolution of the university, alongside its technological adoption and pertinent information related to the evolution of wireless communication from 1G to 5G, with a primary focus on 5G within the university context.

Next, the section on research methods explains the empirical research process in more depth. Findings from the empirical study are then detailed and analyzed in the subsequent section. Finally, the conclusion synthesizes the study's key findings, acknowledges its limitations, and proposes avenues for future research.
Figure 4. Structure of the study.
2 Literature Review

Research on the integration of 5G technology within university campuses and its impact on various aspects of education remains relatively limited in the existing literature. Despite the integration of 5G technology across sectors such as manufacturing, automotive, healthcare, and utilities, among others, its adoption within university settings has been slower, leading to a significant gap in knowledge. This gap presents an opportunity for further exploration to understand the theoretical foundations, practical implications, and potential benefits of 5G technology within the university context. The subsequent sections will explore the existing literature to assess the current state of knowledge, explore the potential applications of 5G technology within university campuses, and identify avenues for future research in this area.

- Systematic Literature Review Approach

The systematic literature review (SLR) undertaken for this study was guided by a central research question and followed a structured approach to identify, select, and synthesize relevant studies, this approach aims to provide a step-by-step process to consolidate a literature relevant to the research topic

Step 1: Research Question and Subquestions:

Table 1. SLR Questions

<table>
<thead>
<tr>
<th>Systematic Literature Review Questions</th>
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<tbody>
<tr>
<td>• Central question RQ1: How does 5G hyper-connected university campus enhance the education experience?</td>
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<tr>
<td>• RQ1.1: How has the evolution of universities and technology integration set the foundation for advanced connectivity like 5G?</td>
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<td>• RQ1.2: In what ways can 5G technology support the development of smart university campuses and the University 4.0?</td>
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<tr>
<td>• RQ1.3: What are the specific use cases and case studies of 5G in university settings required for Industry 4.0?</td>
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Step 2: Identifying Key Search Terms and cluster

Utilizing a combination of focused and broader search terms ensured a comprehensive capture of relevant literature. Key search terms included focused and broader terms:

- **Focused Terms:** “5G technology”, “5G Education”, “Smart University campus”, “Industry 4.0”, “Mobile Communication Evolution”, “5G University Case Studies” “5G University Use Cases”
- **Broader Terms:** “Digital Transformation in Education”, “University 4.0”, “University Evolution”, “University Digital Transformation”

The Keywords Cluster component in the systematic literature review process helps in organizing and visualizing the search terms to ensure an efficient literature search. The clustering aids in capturing the breadth of relevant literature and ensures that no significant area is overlooked. This systematic approach is particularly important for a topic like 5G technology on university campuses, which spans multiple intersecting fields.

Table 2. SLR Keywords Cluster

<table>
<thead>
<tr>
<th>Cluster</th>
<th>Description</th>
<th>Keywords</th>
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<tr>
<td>University Evolution and Foundations</td>
<td>This cluster explores the historical and foundational aspects of universities, focusing on how they have evolved and integrated new technologies over time. It sets the context for understanding how universities are prepared for the adoption of 5G.</td>
<td>- University Foundations and Evolution&lt;br&gt;- Digital Transformation in Universities&lt;br&gt;- University 4.0</td>
</tr>
<tr>
<td>Smart Universities</td>
<td>This cluster addresses the broader concept of smart universities, which encompasses the integration of various advanced technologies, including 5G, to create intelligent and connected campus environments.</td>
<td>- Smart Education&lt;br&gt;- Smart University Campus</td>
</tr>
<tr>
<td>5G Technology</td>
<td>This cluster focuses on the core theme of the study; how 5G technology is being applied in educational settings, particularly in university campuses. The terms in this cluster are directly related to the primary research question.</td>
<td>- 5G Technology&lt;br&gt;- 5G Education&lt;br&gt;- Mobile Communication Evolution&lt;br&gt;- 5G University use cases</td>
</tr>
</tbody>
</table>
Step 3: Defining Inclusion and Exclusion Criteria

To streamline the search process and ensure relevance, several search restrictions were applied. Publications were required to be in the English language and published between 1980 and 2024. This time was chosen to encapsulate successive waves of ICT development in higher education, thus providing a comprehensive understanding of the evolution of technology within academic settings.

Table 3. SLR Inclusion Criteria

<table>
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<th>Inclusion Criteria</th>
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<tr>
<td>• Publications in English</td>
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<tr>
<td>• Studies published between 1980 and 2024</td>
</tr>
<tr>
<td>• Relevant to 5G technology in education, smart universities, and digital transformation in higher education</td>
</tr>
<tr>
<td>• Scholarly sources such as peer-reviewed journal articles, conference papers, book chapters, and other academic publications</td>
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</table>

Step 4: Selecting Databases

Key databases were selected to ensure a wide and comprehensive coverage: Scopus, Web of Science, Google Scholar, IEEE Xplore, LUT Primo

Step 5: Conducting Literature Search

A structured search was conducted in the selected databases using the defined search terms. Boolean operators (AND, OR) were employed to refine the search queries. An example search string used was:

“(“5G technology” OR “5G education” OR “5G university campus”) AND (“smart university” OR “smart campus”)”

Step 6: Screening and Filtering
The initial search yielded a large number of publications. A two-stage screening process was employed:

- Title and Abstract Screening: Initial filtering was done based on relevance to the research question.
- Full-Text Screening: Detailed examination of the remaining articles to ensure they met the inclusion criteria.

**Step 7: Selecting the Final Set of Studies**

After the screening, a final set of 110 studies was selected for detailed analysis. The selection process involved, removing duplicates, assessing methodological quality, and ensuring diversity in study focus and methodology.

**Step 8: Data Extraction and Synthesis**

Data from the selected studies were extracted using a standardized form. Key information included: study objective, methodology, findings related to 5G technology in education and the university campus, and implications and future research directions.

The extracted data were synthesized to provide an overview of the current state of knowledge and to identify gaps and future research opportunities.

**Step 9: Presenting the Results**

The results of the systematic literature review are presented in the following sections, providing insights into the evolution of the university campus, technology integration and deployment of 5G technology in university campuses, its potential applications, and the impact on the education experience.

The figure below illustrates the methodology employed to construct the literature review section.
2.1 University Foundations and Evolution

The following chronological history delves into Figure 1 from the background section, providing an in-depth exploration of the university's historical evolution spanning centuries.

1. Foundation Period

1.1. Medieval Foundations (11th - 14th century)
The concept of universities first emerged in medieval Europe, most of the prevalent universities began as Cathedral schools with higher education primarily to those of the clergy or privileged few (British Literature Wiki 2013). Additionally, students shared a common characteristic, they were exclusively male. Girls received minimal attention from the educational system during the Middle Ages and education focused on religious and classical subjects like theology and language with institutions like the University of Bologna (1088) and the University of Paris (Vest 2020).

Table 4. Medieval field of studies

<table>
<thead>
<tr>
<th>Field 1: Trivium</th>
<th>Field 2: Quadrivium</th>
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<tr>
<td>1. Grammar</td>
<td>4. Arithmetic</td>
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<td>2. Rhetoric</td>
<td>5. Astronomy</td>
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<tr>
<td>3. Logic</td>
<td>6. Geometry</td>
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<td></td>
<td>7. Music</td>
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</table>

Like today’s modern higher education institutions, medieval universities trained young students for a future job; however, the career that awaited students after the completion of their studies was within the Catholic church. Modern universities allow students to pursue various career paths, medieval universities mainly focused on providing a "liberal arts" education centered around seven academic subjects (British Literature Wiki 2013).
1.2. Renaissance and Expansion (15th - 17th century)

Figure 7. Meeting of doctors at the University of Paris (Wrangel 1938).

The Renaissance, a period characterized by cultural, artistic, political, and economic revitalization after the Middle Ages, witnessed significant advancement in education, notably the creation of universities (Sacchini 2022). Before this period, the Church largely controlled education. However, the Renaissance, fueled by humanism, fostered innovation that led to the foundation of new subjects and expansion of the curriculum, including subjects like law and medicine alongside traditional religious studies (Sacchini 2022).

The physical infrastructure of universities also improved with the addition of courtyards and libraries. Johannes Gutenberg’s invention of the printing press revolutionized access to knowledge by making books more affordable and widespread (Jarus and published 2022). Moreover, the Renaissance redefined the purpose of education, shifting its focus from serving the clergy and nobility to being perceived as a tool for individual growth and social mobility (Sacchini 2022).

2. Industrial Revolution (18th - 19th century)

During the Industrial Revolution, universities underwent significant transformations in response to the changes in the society and economic landscape. As industrialization swept
across Europe and North America, universities adapted their structure, curriculum, and societal position to suit the demands of the emerging industrial age (Perkin 2002).

One notable impact of the Industrial Revolution on universities was the expansion of scientific and technical education. With the rise of industrialization came a growing demand for skilled workers in fields such as engineering, chemistry, and physics (Beno 2019). To address this demand, universities began to broaden their curriculum to include these subjects, establishing departments and programs dedicated to scientific and technical education (Britannica 2024).

In addition to expanding their curriculum, universities also invested in infrastructure to accommodate the growing student population and the demand for specialized facilities. New lecture halls, laboratories, libraries, and dormitories were constructed to support the expanded curriculum and research activities. These infrastructure developments transformed university campuses and laid the foundation for modern academic institutions (Beno 2019).

Moreover, the Industrial Revolution spurred closer ties between universities and industries. Universities forged partnerships with industry to facilitate research collaboration, technology transfer, and workforce development. Industry-sponsored research projects became more common, providing funding and opportunities for students and faculty to engage in real-world problem-solving (Ankrah and Al-Tabbaa 2015).

3. Modern Era (20th century)

The Modern Era of the 20th century marked a transformative period for universities, characterized by rapid advancements in information technology (IT) that revolutionized every aspect of higher education.

The introduction of computers, the internet, and digital communication fundamentally altered the educational landscape, offering new opportunities and challenges for universities worldwide. These technological innovations enabled universities to expand their reach beyond physical boundaries, facilitating collaboration across disciplines, institutions, and geographical locations (Holbrooke 2004)
IT transformed traditional pedagogical methods, instructional delivery, and the adoption of digital tools, online learning platforms, and multimedia resources revolutionized how knowledge was imparted and acquired within university settings (Allen and Seaman 2017). Furthermore, IT played a fundamental role in driving research and innovation within universities. The digitization of research processes, data collection, and analysis accelerated the pace of scientific discovery and interdisciplinary collaboration. High-performance computing, simulation technologies, and digital libraries revolutionized how research was conducted, leading to breakthroughs in diverse fields such as medicine, engineering, and social sciences (Noble 2002).

Administratively, the IT infrastructure modernized university operations and management. Integrated student information systems, electronic databases, and online administrative platforms streamlined administrative processes, enhancing efficiency and accountability (Noble 2002).

The integration of IT emerged as the defining feature of universities' evolution during the Modern Era. It transformed higher education by expanding access, fostering collaboration, and driving innovation across all facets of university life (Noble 2002).

4. Digital Age

4.1. Information Age (late 20th century - present)

The late 20th century saw the beginning of the information age, marked by the proliferation of the Internet and digital communication technologies. Universities swiftly embraced these technological advancements, leveraging the power of digital networks to facilitate global connectivity, knowledge sharing, and collaboration (Kizilhan and Bal 2016). The transition to online learning platforms revolutionized the delivery of education, offering students greater flexibility and accessibility to educational resources (Weller 2011). Furthermore, digital research methodologies and collaborative tools facilitated interdisciplinary research endeavors, accelerating scientific discovery and innovation within academic institutions (Borgman 2007).
4.2 Digital Transformation (21st century)

The 21st century presented a new era of digital transformation for universities, as technological advancements continued to reshape the landscape of higher education. With the increase of mobile devices, cloud computing, and big data analytics, universities embraced digital transformation initiatives to optimize administrative processes, improve student services, and enhance learning outcomes (Weller 2011). The rise of Learning Management Systems (LMS) and educational apps facilitated personalized and adaptive learning experiences for students, catering to diverse learning styles and preferences (Weller 2011).

4.3. Advanced Technologies and Innovation (present - future)

In the present era of advanced technologies and innovation, universities are at the forefront of pioneering research and development initiatives that harness the power of emerging technologies such as artificial intelligence, virtual reality, and blockchain. These technologies hold the potential to re-think teaching, learning, and research processes, enabling immersive and interactive learning experiences (Johnson et al. 2016). Universities are investing in state-of-the-art facilities and collaborative research centers to drive innovation and entrepreneurship, promoting a culture of creativity and experimentation (Etzkowitz 2008).

Partnerships between universities and industry leaders continue to drive innovation and research in advanced technologies. For example, Carnegie Mellon University (CMU) partnered with Uber Advanced Technologies Group (ATG) to establish the Uber Center for Advanced Technologies, focusing on research in autonomous vehicles and artificial intelligence (Spice et al. 2015). These collaborations facilitate technology transfer, talent development, and knowledge exchange, driving economic growth and societal impact.
2.2 Digital Transformation in Universities

The evolution of technology infrastructure in universities has been a captivating journey, transforming the traditional classroom into a dynamic, tech-infused learning environment (Chaudhary 2023). This narrative traces the trajectory from the absence of technology to the integration of virtual realities, robotics, innovation labs, and 5G connectivity (Floridi 2014). The timeline below shows key technology innovations introduced to universities.

![Timeline of technology evolution on university campus.](Khourdajie 2008)

Technological advancements have consistently transformed education. In ancient civilizations, papyrus enabled effective dissemination of knowledge, exemplified by the Library of Alexandria's extensive collections (Ryholt 2021). The printing press, invented by Johannes Gutenberg around 1440, democratized access to knowledge by making books more affordable and expanding educational opportunities (Freeman 1981).

The telegraph, introduced in the early 19th century, transformed communication, allowing rapid exchange of academic ideas and research (Tympas 2001). Guglielmo Marconi’s early
20th-century radio transmissions further expanded access to educational content through radio broadcasts (MIT Press 1991).

The mid-20th century brought projectors and overhead transparencies, enhancing traditional lectures with multimedia elements. The advent of email provided efficient academic communication, facilitating collaboration (Wadi and Draxler 2002). The 1980s saw personal computers and multimedia tools enter classrooms, fostering interactive learning (Wadi and Draxler 2002).

The 1990s integration of the Internet and the rise of the World Wide Web (WWW) transformed university communication and research, leading to smart classrooms and the birth of e-learning (Chukwunonso et al. 2013). In the 21st century, mobile technologies and Learning Management Systems (LMS) enabled asynchronous learning and remote education (Chukwunonso et al. 2013).

Recent advancements in Virtual Reality (VR), Augmented Reality (AR), and robotics are now transforming experiential learning, providing immersive and hands-on experiences. The arrival of 5G connectivity offers seamless communication and collaboration, even for bandwidth-intensive applications (Rullo 2022).

The evolution of technology infrastructure at universities reflects an ongoing commitment to enhancing the educational experience. From papyrus to virtual realities, each technological leap has brought new possibilities and challenges. As we embrace the latest advancements, the journey continues, promising an ever-evolving landscape of innovation in higher education.

2.3 Smart Education

Smart education represents a transformative approach to learning, leveraging information and communication technologies (ICTs) to enhance educational outcomes. Described as the skillful and unified application of technologies to achieve educational goals through an appropriate teaching method, smart education comprises a broad spectrum of technological advancements aimed at fostering intelligent learning environments (Demir 2021).
Various scholars have offered nuanced definitions of smart education, emphasizing its multifaceted nature and its emphasis on personalized learning experiences. Zhu et al. (Zhu et al. 2016) describe it as “the concept of learning in the digital age,” highlighting the integration of technology into the learning process. Bajaj and Sharma (Bajaj and Sharma 2018) stress the importance of personalized learning, emphasizing its accessibility anytime and anywhere, transcending the boundaries of traditional classrooms.

Based on different information technologies enabling smart education a layered model is developed as shown in figure 9 the outer layers support the core as a base for the realization of smart education (Demir 2021).

![Smart education framework technologies (Demir 2021).](image)

In essence, smart education transcends mere technological integration; it embodies a paradigm shift in teaching and learning approaches, emphasizing adaptability, personalization, and innovation (Demir 2021).

2.3.1 Smart Education Framework

In response to the mobilization of global networks advocating for an integrated ICT in Education (ICTE) agenda, UNESCO has developed a comprehensive framework aimed at
addressing the multifaceted challenges and opportunities presented by the intersection of education, artificial intelligence (AI), and the fourth industrial revolution (4IR) (UNESCO IITE 2022).

At the core of UNESCO's framework are six interrelated policy themes that encapsulate the key areas of focus for smart education policies:

1. **Infrastructure**: addressing the technological infrastructure, including access to high-speed internet connectivity and advanced telecommunications systems.

2. **Curriculum and Pedagogy**: emphasizing innovative teaching methodologies to enhance learning outcomes and adapt to evolving educational needs.
3. **Digital Education Resources**: Promoting open educational resources (OER) and interactive learning materials, to facilitate equitable access to quality education.

4. **Skills and Competencies**: Fostering the acquisition of digital literacy skills and competencies necessary for active participation in the digital economy and society.

5. **Governance**: Establishing robust governance frameworks to guide policy implementation in the delivery of smart education initiatives.

6. **Management and Administration**: Streamlining administrative processes to optimize the efficiency and effectiveness of educational institutions in the digital age.

Additionally, the framework identifies three enablers as policy adoption mechanisms:

1. Leadership
2. Finance, and partnerships
3. Research, and innovation

While the framework underscores the importance of robust technological infrastructure across its domains to support smart education practices, it does not delve into the pivotal role of 5G as a mobile technology in realizing these aspirations. This omission underscores the need for further exploration into the unique capabilities and contributions of 5G technology in advancing the objectives of smart education within the framework's broader context.

### 2.4 Smart University Campus

The concept of the smart campus arises from the evolving landscape of higher education, driven by the possibilities of digital transformation incorporating cutting-edge technologies to create an interconnected, intelligent, and efficient learning environment (Polin et al. 2023a) this ecosystem is reflected in figure 11. Often likened to scaled-down versions of smart cities, smart campuses function as experimental environments for exploring, developing, and integrating smart technologies alongside their conventional roles in education, research, and innovation (Polin et al. 2023a)
Several technologies serve as the building blocks for a smart university campus, enabling seamless connectivity, data-driven decision-making, and enhanced user experiences. IoT devices are essential for gathering and transmitting live data to monitor and manage various operations. Artificial intelligence (AI) and machine learning (ML) algorithms analyze this data to derive valuable insights, optimize campus operations, and personalize learning experiences. Augmented reality (AR) and virtual reality (VR) technologies create immersive learning environments, while cloud computing infrastructure facilitates data storage, processing, and accessibility.

2.5 Role of 5G in Smart University Campus

To keep pace with the new demands of contemporary education and the imperative to remain technologically adept, higher education institutions face the necessity of crafting and implementing comprehensive wireless infrastructure solutions (Kadia 2024). 5G technology provides capabilities and value for specific use cases and applications. To derive maximum
benefit from Industry 4.0 and the smart IoT revolution, universities can position themselves as pioneers of digital transformation, not only within their academic sphere but also as catalysts for innovation in collaboration with enterprise partners (Kadia 2024).

The integration of fifth-generation (5G) technology within smart university campuses is increasingly recognized as pivotal for advancing educational environments (Rullo 2022). 5G provides enhanced connectivity, ultra-low latency, and massive device support, thereby enabling seamless communication, real-time interactions, and immersive experiences such as augmented reality (AR) and virtual reality (VR). Advanced network infrastructure serves as an enabler for new developments, applications, innovation, and personalized learning experiences within smart education environments (Rullo 2022).

Smart campuses, driven by the integration of advanced technologies, including 5G, are at the forefront of seamlessly incorporating ICT into campus infrastructure to optimize operations, enhance learning experiences, and foster sustainability (Kadia 2024). At their core, smart campuses aspire to make significant contributions across four essential domains: economy, society, environment, governance, and technology.

![Smart campus domains](image)

Figure 12. Smart campus domains (Polin et al. 2023a).

In the economy domain, 5G facilitates high-speed data transmission and seamless connectivity, enabling universities to modernize programs and infrastructure to align with Industry 4.0 imperatives and enhance their competitive edge (Polin et al. 2023b).

In the society domain, 5G enables immersive learning experiences, fosters collaboration among students and faculty, and enhances campus safety through real-time monitoring
systems, thereby enriching community engagement and promoting social responsibility (Polin et al. 2023b).

Within the environment domain, the deployment of 5G technology supports IoT-based environmental monitoring and smart energy management solutions, driving initiatives for environmental sustainability and resource optimization (Polin et al. 2023b). In the governance domain, 5G enhances decision-making processes, cybersecurity measures, and data governance practices, empowering administrators with timely insights for efficient service management and ensuring the effective operation of campus infrastructure (Polin et al. 2023b).

These four domains are underpinned by a comprehensive perspective on digital technology and data, creating an integral fifth category that interacts significantly with the other four within smart campuses. For example, big data management involves the extensive and varied information collected, stored, and organized to support campus operations. Digital technologies, including sensors, IoT, AI, 5G, cloud computing, and blockchain, are crucial in facilitating big data management and being a platform for smart campus functions (Polin et al. 2023b)

2.6 University 4.0

The concept of University 4.0 draws inspiration from the paradigm of Industry 4.0, reflecting the transformative changes occurring in higher education systems in response to the digital surge and evolving societal needs (Exposito and Gueye, 2020). This evolution can be delineated into four distinct stages, each corresponding to a significant industrial revolution as shown in the figure below.
University 4.0 represents the latest stage in this evolution, characterized by the integration of digital technologies and biotechnology and partnerships with high-tech industries into higher education (Exposito and Gueye 2020). It prioritizes diverse knowledge across multiple variables, particularly emphasizing information and communication technologies (ICT) and biotech, fostering creativity and global competencies among students. University 4.0 operates as a hub for research, innovation, and entrepreneurship, driving sustainable development in higher education. (Exposito and Gueye 2020)

The emergence of University 4.0 reflects the importance for universities worldwide to adapt to the evolving economic landscape, characterized by digital disruption and significant shifts in labor markets. As the nature of employment undergoes rapid transformation, with automation rendering many traditional occupations obsolete, students must be equipped with skills and qualifications relevant to the dynamic digital environment (Dewar 2024).

Consequently, there is a growing emphasis on applied university research, fostered through deep collaborations with industry, high-tech partnerships, and initiatives like accelerator programs and incubators. The accelerated pace of technological innovation necessitates swift
translation of research ideas into commercial outcomes, as traditional methods are deemed too time-consuming (Dewar 2024).

In the context of University 4.0, higher education institutions are well-positioned to serve as central hubs for innovation and collaboration due to their blend of talented individuals, advanced research facilities, and ample physical space. This positioning enables them to facilitate the co-location of various industries, fostering a conducive environment for startup ventures to thrive (Dewar 2024).

2.7 Mobile communication evolution: from 1G to 5G

In the past few decades, mobile communication has witnessed remarkable advancements, transforming the way we connect, communicate, and access information. From the early days of brick-sized mobile phones with limited capabilities to today’s connected society, the journey of mobile networks has been nothing short of astonishing (Patel 2022). From a historical perspective, as illustrated in the following figure, each generation of cellular standards has developed around specific key use cases: 1G focused on voice services, 2G enhanced voice and introduced text messaging, 3G integrated voice with affordable mobile internet, and 4G provided high-capacity mobile multimedia. 5G aims to deliver extreme broadband and ultra-reliable, low-latency connectivity, enabling the programmable world (Moore 2023).

Figure 14. From 1G to 5G. Adapted from (Guevara and Auat Cheein 2020).
The evolution of mobile communication, starting with 1G in the 1940s, laid the foundation for modern networks with basic voice calls (Moore 2023). The 1990s saw the advent of 2G, introducing digital communication and SMS, revolutionizing mobile telecommunications (Moore 2023).

With 3G in the early 2000s, mobile internet became widespread, enabling web browsing and multimedia access (Moore 2023). The arrival of 4G around 2010 brought faster data speeds, real-time video streaming, and the growth of IoT devices (Moore 2023).

The introduction of 5G transcends faster internet speeds, supporting numerous devices and data-intensive applications like VR/AR and IoT. In education, 5G can transform university campuses, integrating advanced technologies and enhancing learning experiences, preparing students for Industry 4.0 (Moore 2023).

2.8 5G Technology Overview: What is 5G?

5G represents the fifth generation of mobile wireless telecommunication technology, marking a significant technological advancement with entirely new components: new spectrum frequencies, new radio systems, a new core network, and updated global wireless standards following 1G, 2G, 3G, and 4G networks. This new era of 5G technology is set to revolutionize business operations and daily activities, offering substantial productivity enhancements through three key capabilities. (Accenture 2022):

- Enhanced mobile broadband (eMBB)
- Mission-critical services (MCS)
- Massive Internet of Things (mIoT)
Enhanced Mobile Broadband (eMBB) is a core feature of 5G technology, providing high-speed internet with greater bandwidth and improved network capacity (Dangi et al. 2021). This supports applications such as high-definition video streaming, virtual reality (VR), and immersive gaming, which can significantly enhance educational experiences on university campuses (Dangi et al. 2021). Advanced antenna technologies like massive MIMO enable efficient use of spectrum resources, further boosting network capacity and throughput, making eMBB a transformative tool in education (Marzetta et al. 2016).

Mission Critical Services (MCS) in 5G deliver ultra-reliable, low-latency communication, crucial for time-sensitive applications (Akpakwu et al. 2018). In a university setting, MCS can support applications like remote labs, real-time simulations, and secure data transfer, vital for fields such as healthcare, engineering, and public safety education. These capabilities enable innovative solutions and enhance the digital transformation of academic environments (Accenture Strategy 2021).
Massive Internet of Things (mIoT) extends connectivity to a vast array of devices and sensors, integrating physical and digital worlds seamlessly (Akpakwu et al. 2018). For universities, 5G supports the scalability needed for connected devices, from smart classrooms and wearables to campus-wide infrastructure components (Gupta and Jha 2015). The high connection density facilitated by 5G accommodates the growing number of IoT devices, enhancing smart campus initiatives and enabling advanced research in fields like environmental monitoring and industrial IoT (Accenture Strategy 2021).

The enhanced capabilities of 5G cater to diverse applications and use cases as shown in figure 16. They promise to transform the way we connect, communicate, and interact with the world around us.

At its core, 5G technology leverages advanced radio access technologies and innovative architectural elements. The six building blocks shown in figure 17 form the backbone of 5G's capabilities, enabling it to drive further economic growth and foster pervasive digitalization within a hyperconnected society. This entails not only ensuring universal connectivity for individuals but also extending connectivity to a myriad of devices, thereby laying the foundation for a hyperconnected society (Nokia 2021a).
5G technology supports the complex infrastructure of university campuses, accommodating high numbers of students, devices, and continuous operations. A key component is the utilization of the millimeter-wave (mmWave) spectrum, which significantly boosts network capacity and performance due to its high bandwidth characteristics (Andrews et al. 2014). Additionally, Massive MIMO, coupled with beamforming technology, employs multiple antennas are deployed at both the transmitting and receiving points, improving spectral efficiency and extending targeted coverage (Marzetta et al. 2016).

The architecture within the 5G ecosystem also features Edge Cloud, facilitating low-latency communication by hosting demanding applications and executing critical network functions (Satyanarayanan 2017). Multi-connectivity allows simultaneous connections to multiple radio access technologies, ensuring seamless transitions between legacy and 5G networks (McCarthy 2020).

Network slicing emerges as a pivotal technique, enabling the creation of virtual networks tailored to specific applications and service level agreements (SLAs), optimizing resource allocation and network utilization (McCarthy 2020). Furthermore, connectionless communication streamlines protocols and reduces signaling overhead, lowering the cost of IoT connectivity and supporting numerous connected devices (McCarthy 2020).

Figure 17. 5G enabled by new technology building blocks (Nokia 2021b).
capabilities not only enhance connectivity but also support the production of knowledge, innovation, and societal contributions, making university campuses more efficient and technologically advanced.

2.9 5G compared to other technologies

It all started with the advent of 1G, the foundational network that facilitated mobile voice communication. The arrival of 5G marks an even more exciting phase, as it promises to interconnect everything, humans, machines, objects, and devices (Johnson 2020).

The principal differences between these wireless technologies are particularly concerning speed, latency, coverage, and bandwidth (Johnson 2020).

The idea of transitioning from traditional Wi-Fi to a 5G hyperconnected university campus is increasingly relevant in today’s society due to the substantial improvements in speed, latency, coverage, and bandwidth that 5G technology offers. Currently, 4G networks provide maximum speeds of up to 100 Mbps, while real-world performance averages around 35 Mbps. In contrast, 5G promises speeds nearly 100 times faster, with theoretical peaks of approximately 24 Gbps and real-world speeds ranging from 50 Mbps to 3 Gbps. This
dramatic increase in speed facilitates high-definition video streaming, virtual reality (VR) experiences, and immersive gaming, significantly enhancing the user experience on university campuses (Johnson 2020). Additionally, 5G’s reduction in latency to about 1 millisecond supports real-time applications such as cloud-based AI for self-driving cars, which is crucial for innovative educational tools and research applications (Johnson 2020).

Furthermore, the coverage and bandwidth advantages of 5G address the limitations faced by traditional Wi-Fi in large university settings. Despite a decade of 4G deployment, many rural and remote areas still struggle with inadequate coverage. While 5G is still expanding, its potential for high, medium, and low-band implementations promises to eventually provide comprehensive coverage (Johnson 2020). Unlike Wi-Fi, which struggles with obstructions like buildings and trees, 5G offers more reliable and extensive coverage across large campuses (Nokia 2021b).

The enhanced bandwidth of 5G, utilizing multiple frequency bands, allows for more efficient spectrum usage and higher capacity, supporting a greater number of devices and data-intensive applications. This is critical for modern universities that require robust, high-capacity networks to support diverse educational and research activities (Johnson 2020). Therefore, transitioning to a 5G hyperconnected campus is vital for universities to meet the growing demands for connectivity, fostering innovation, and preparing students for the digital future.

2.10 5G Case Studies and Use Cases on University Campuses

In the years 2015 and 2016, during the early stages of 5G development, many leading academic institutions worldwide launched projects focused on researching 5G technology (Hardesty 2022). The more developed use cases center around smart campus applications such as heating, security monitoring, AR, VR learning, and industrial use cases for manufacturing and logistics. There is currently research on applications for healthcare, transportation agriculture, and construction business among other sectors thanks to investment in technology (Hardesty 2022).
These also provide students and professors the opportunity to further research in specific fields of study, as well as better functioning e-learning applications and sustainability for the universities themselves. The table below summarizes some of the university references where 5G has been leveraged for research projects.

Table 5. References of Universities adopting 5G technology (Fierce Telecom 2022).

<table>
<thead>
<tr>
<th>University</th>
<th>Use Cases or Projects</th>
<th>Main Industry</th>
<th>Partnership</th>
</tr>
</thead>
</table>
| **University of Surrey, UK**    | - 5G Innovation Centre (5GIC), a world-leading research facility focused on developing and testing 5G technologies  
                                      - Development of low-latency communication systems for autonomous vehicles and remote medical diagnostics | - Healthcare  
                                      - Transportation  
                                      - Agriculture | - Samsung Electronics and Vodafone  
                                      - 26 corporate members and 250 small and medium-size enterprises |
| **University of Tennessee**     | - Exploring nuclear power plants, deep ocean exploration, or rocket launches, focused on scenarios that students can’t usually get access to because of expense, risk or feasibility.  
                                      - Incorporates AR, VR for educational methodologies and training scenarios.  
                                      - Biometric data is used to assess how actively students engage with course materials, tailoring learning experiences accordingly. | - Digital learning  
                                      - Military applications  
                                      - Healthcare | AT&T |
| **University of Connecticut**  | - 5G+ for science and entrepreneurship programs.  
                                      - Data science technology incubator, and an entrepreneurship program that helps students create products | - Data science  
                                      - Entrepreneurship  
                                      - Construction | AT&T |
| University of Missouri, and University of Miami | - Establish 5G labs and zones.  
- Enhance educational curriculums across scientific and engineering disciplines.  
- Focus on smart agriculture and smart cities.  
- Implement 5G for real-time data collection and analysis. | - Smart agriculture  
- Smart cities | AT&T |
| Caltech and Penn State | - Drones testing and weather monitoring in real time | - Sustainability | Verizon |
| Arizona State University | - 5G Innovation Hub.  
- Addresses critical issues in healthcare, climate change, and education.  
- Develops 5G-driven solutions to bridge the digital divide.  
- Enhances access to telemedicine and remote education. | - Healthcare  
- Sustainability  
- Education | Verizon |
| Purdue University Airport | - Private 5G network for airport operations.  
- Enhances communication between aircraft and ground operations.  
- Streamlines airport logistics. | - Aviation | Ericson |
| University of Technology Sydney | - 5G Innovation Lab for Industry 4.0 applications.  
- 5G technology for industrial automation.  
- Enhances robotic and human interaction. | - Manufacturing  
- Automotive  
- Robotics | Nokia |
| Aalborg University | - 5G Smart Lab for robotics  
- Development of 5G Autonomous Mobile Robots. | - Logistics  
- Manufacturing  
- Robotics | Nokia and 11 industrial and technology |
<table>
<thead>
<tr>
<th>University</th>
<th>Description</th>
<th>Partners/Projects</th>
</tr>
</thead>
</table>
| **Stuttgart University**                       | - Integrate 5G, Edge-Cloud, Digital Twin, Mobile Robotic Systems  
- 5G research center simulates the smart factory of the future  
- Indoor localization, mobile video applications, real-time configuration of production systems, work safety and advanced human-robot collaboration systems.  
- Automotive - Manufacturing  
- Healthcare - Transportation - Education - Energy  
- Nokia and an ecosystem of around 35 participating enterprises |                                                                                   |
| **University of Glasgow**                      | - Smart campus applications, such as real-time monitoring of energy usage, traffic management systems, and enhanced campus security  
- Leading research projects in collaboration with industry partners for the development of 5G and 6G  
- Smart Machibary (Autonomous excavator)  
- Telecommunication - Manufacturing - Sustainability - Construction | Nokia and Collaborations with a consortium of 14 partners has been formed to take forward proposals for the living laboratory. |
| **University of Oulu**                         | - Atonomous vehicles, real-time traffic management systems, and immersive educational experiences  
- 5G testbed for technologies, enabling researchers to explore novel use cases and applications.  
- 5G healthcare in Africa  
- University of the Future’ project  
- Healthcare - Agriculture - Sustainability - Smart City | Nokia                                                                 |
| **Tokyo Insitute of Technology**               |                                                                                                                                  |                                                                                  |
| **University of Cape Town**                    |                                                                                                                                  |                                                                                  |
Through strategic collaborations with public organizations, industry and technology companies, universities create an ecosystem where theoretical knowledge integrates with practical applications. These partnerships enable students to transition from passive recipients of information to active participants, engaging in experiential learning with advanced technologies and benefiting from valuable professional networking opportunities. This synergy catalyzes innovation and facilitates the incorporation of 5G technology into educational frameworks. By equipping students with essential competencies and insights, such collaborations effectively bridge the gap between academia and industry, preparing students to excel in the landscape of Industry 4.0.

- **Literature Review Conclusion**

The evolution of universities from their foundational principles to the digital age reflects a deep transformation in higher education. Initially, universities focused on disseminating knowledge through traditional means, but the digital revolution has significantly altered this landscape. The transition from papyrus to virtual reality illustrates how digital transformation has integrated advanced technologies into educational practices, enhancing accessibility, engagement, and interactivity.

This evolution sets the stage for the emergence of Smart Education, where intelligent systems and data-driven approaches personalize learning experiences and improve educational outcomes. Despite these advancements, the pace of change within universities has not kept up with the rapid technological advancements seen in the industry, particularly since the mid-2010s.

The concept of a Smart University Campus leverages the potential of 5G technology to create an interconnected and forward-thinking educational environment. 5G's high-speed, low-latency capabilities facilitate the development of advanced use cases, including smart classrooms, connected libraries, and hands-on learning environments such as smart factories and automation labs. These innovations enable remote learning, real-time data analytics, and immersive experiences through augmented and virtual reality.
The role of 5G in this transformation is key, as it supports the infrastructure necessary for these advanced applications, fostering a more engaging and efficient learning experience for students and providing professors with practical spaces to showcase real-world technologies and innovate their teaching methods.

Despite the benefits of 5G and the references shown in table 5, universities face significant challenges in keeping pace with industry advancements. Without robust industry partnerships and a proactive approach to integrating 5G-enabled technologies, universities risk becoming obsolete (Wessels and Van Wyk 2022).
3 Methodology

The research methodology involves systematic and structured decisions regarding how data is collected and analyzed, which may include qualitative, quantitative, or mixed methods. Decisions regarding sampling, data collection, and analysis techniques are made based on research objectives, which are influenced by the type of research and academic goals (Thakur 2021). This Master’s thesis employed a mixed research methods approach to investigate how 5G technology enhances the educational experience on university campuses. By integrating both quantitative and qualitative methods, this study aims to provide a comprehensive understanding of the subject matter. This section will delve into the chosen data collection methods, the data analysis techniques and results.

3.1 Data Collection

Mixed research methods, incorporating both quantitative and qualitative methodologies, provide a holistic view of the research question. By integrating both approaches, this study seeks to leverage the strengths of each method to gain a deeper understanding of the impact of 5G technology on the university campus environment.

The rationale for selecting mixed methods is multifaceted. 5G is the latest wireless technology, pivotal in enabling the digital future of various industries. Despite its transformative potential, the deployment of this technology in educational settings, particularly university campuses, remains limited. Thus, a comprehensive investigation requires capturing diverse perspectives and experiences.

3.1.1 Quantitative Study

Survey

Quantitative research employs mathematical, statistical, or computational techniques to collect, analyze, and interpret numerical data (Streefkerk 2019). For this study, a survey
method was employed serving as the primary quantitative data collection tool. The survey conducted was exploratory and descriptive in nature, incorporating both open-ended and closed-ended questions to gather qualitative insights and quantitative data.

Survey Protocol

The master’s survey aimed to explore how the integration of 5G technology can enhance the educational experience within a university campus. It sought to understand current challenges in connectivity and technology adoption, assess awareness and understanding of 5G technology, explore potential benefits and challenges associated with its implementation, and investigate the role of industry partnerships and innovation in advancing educational practices.

The survey targeted key stakeholders within the university community, including students, professors, administrative staff, researchers, and alumni. A total of twenty-four questions were formulated for the survey, and distributed through various channels including email, social media, professional networks, and referrals. The sampling target comprised 100 respondents over a one-month period.

The survey consists of five main sections:

1. Demographics: Collects basic demographic information and role within the university community.
2. Current Connectivity and Technology Challenges: Assesses the level of internet connectivity on campus, identifies challenges, and explores areas for improvement in technology adoption.
3. 5G Awareness: Evaluates the level of understanding and awareness of 5G technology among respondents.
4. Industry Partnerships and Innovation: Explores the benefits and challenges of collaborating with companies or government institutions in adopting 5G technology for education.
5. **Gratitude and Follow-up:** Concludes the survey and provides an opportunity for respondents to share contact information for further comments or follow-up interviews.

### 3.1.2 Qualitative Study

**Semi-structured interview**

Qualitative research is a structured empirical investigation aimed at comprehending and interpreting social phenomena by examining subjective experiences, meanings, and perspectives (Streefkerk 2019). In contrast to quantitative research, which emphasizes numerical data and statistical analysis, qualitative research endeavors to reveal in-depth, detailed insights into the intricacies of human behavior, beliefs, and interactions.

Interviews were conducted with professors and university staff involved in the 5G Test Network Finland program, facilitated by Nokia’s 5G technology. Semi-structured interviews were utilized, allowing for flexibility while maintaining a thematic framework. This approach enabled a deeper exploration of the reasons behind the trends observed in the quantitative data.

- **Background**
The interviews serve as part of the thesis research on the role of 5G technology in enhancing the education experience. The interviewer's interest in education and professional involvement with Nokia underscores the significance of this research area. To ensure data protection the identities of the interviewees will remain confidential.

- **Objective**
The interviews aim to gather insights on various aspects, including the current 5G technology infrastructure on university campuses, user experiences, use cases, collaboration opportunities, challenges, future directions, and student involvement.

- **Interview Protocol**
  - **Time:** The interviews were expected to last between 45 minutes to 1 hour.
o **Roles:** The interviewer led the conversation, while the interviewees will openly share their thoughts on the questions addressed by the interviewer.

o **Equipment:** Microsoft Teams was used to conduct the interviews, with recordings later transcribed for data analysis purposes.

- Interview Guide

The semi-structured interview guide encompasses the following main categories:

- Overview of 5G Deployment
- User Experience and Impact
- Use Cases and Applications
- Collaboration and Innovation Opportunities
- Challenges and Considerations
- Future Directions and Opportunities
- Student Involvement and Feedback

**University Campus Observations**

An observation method was also implemented on six selected university campuses participating in the 5G test network deployment in Finland enabled with Nokia’s technology, the aim was to assess the 5G technology infrastructure, use cases enabled, innovative projects developed, and overall awareness of this technology deployment on the university campus. These visits provided firsthand insights into various projects enabled by 5G across different fields of study, including engineering, healthcare, and energy.

**Literature Review**

Additionally, a comprehensive literature review was conducted to provide theoretical insights into the evolution of universities, the application of technology in education, and the emergence of 5G technology. By synthesizing existing literature, this study aims to contextualize its findings within broader academic discourse and identify gaps for further research.
3.2 Data Analysis

The selected data analysis approach for this master's thesis combines, descriptive statistics and abductive reasoning with theme analysis. This approach offers versatility and depth, enabling the exploration of complex phenomena and the extraction of insightful findings. Thematic analysis, a widely adopted method for qualitative data analysis, identifies patterns across raw data, structuring them into meaningful themes. This technique, known for its flexibility, accommodates both inductive and deductive research designs (Caulfield 2019). When unexpected data surfaces, abductive analysis demands creativity in constructing theories that better align with empirical observations (Thompson 2022).

3.2.1 Qualitative Study Analysis - Survey

- Demographics of Participants

Table 6. Role Distribution

<table>
<thead>
<tr>
<th>Role</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>University Alumni</td>
<td>39 %</td>
</tr>
<tr>
<td>Student</td>
<td>27 %</td>
</tr>
<tr>
<td>University professor</td>
<td>19 %</td>
</tr>
<tr>
<td>Administrative staff</td>
<td>8 %</td>
</tr>
<tr>
<td>Other</td>
<td>7 %</td>
</tr>
</tbody>
</table>

The survey included a diverse group of participants, comprising university alumni, students, professors, and administrative staff. This distribution ensures a comprehensive perspective on the impact of 5G technology across different university stakeholders.

Table 7. Age Range

<table>
<thead>
<tr>
<th>Age</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>25-34</td>
<td>34 %</td>
</tr>
<tr>
<td>35-44</td>
<td>30 %</td>
</tr>
<tr>
<td>45-54</td>
<td>17 %</td>
</tr>
</tbody>
</table>
The majority of participants were between the ages of 25-44 (64%), indicating that the respondents are predominantly young to middle-aged adults who are likely to be current or recent members of the academic community.

Table 8. Educational Level

<table>
<thead>
<tr>
<th>Highest level of study</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Master or equivalent level</td>
<td>49 %</td>
</tr>
<tr>
<td>Bachelor or equivalent level</td>
<td>25 %</td>
</tr>
<tr>
<td>PhD</td>
<td>25 %</td>
</tr>
<tr>
<td>Other</td>
<td>1 %</td>
</tr>
</tbody>
</table>

A high percentage of participants hold advanced degrees, with 49% having a Master’s degree and 25% holding a PhD. This indicates a highly educated respondent base, which is beneficial for understanding nuanced views on 5G technology in education.

- Geographic and Institutional Representation

*Global Reach:* Participants came from 44 countries, with a notable majority from Europe (62%), followed by Latin America (26%). This international representation ensures that the findings are globally relevant and not limited to a single region's perspective.

*University Diversity:* Although participants came from various countries, the universities they attended were predominantly European (76%), highlighting Europe as a significant hub for higher education among the respondents. This could influence the perceptions of technological integration based on the advanced infrastructure available in European universities.
Table 9. Fields of Study

<table>
<thead>
<tr>
<th>Faculty / Field</th>
<th>% of Participants</th>
<th>% with Master's Degree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Faculty of Business Administration</td>
<td>26%</td>
<td>35%</td>
</tr>
<tr>
<td>Faculty of Engineering</td>
<td>22%</td>
<td>33%</td>
</tr>
<tr>
<td>Faculty of Humanities and Social Sciences</td>
<td>16%</td>
<td>47%</td>
</tr>
<tr>
<td>Faculty of Natural Sciences</td>
<td>13%</td>
<td>59%</td>
</tr>
<tr>
<td>Faculty of Law</td>
<td>9%</td>
<td>67%</td>
</tr>
<tr>
<td>Faculty of Medicine</td>
<td>7%</td>
<td>83%</td>
</tr>
<tr>
<td>Faculty of Arts</td>
<td>7%</td>
<td>20%</td>
</tr>
</tbody>
</table>

Varied Academic Disciplines: Participants represented a wide range of academic disciplines, with the highest participation from the Faculty of Business Administration (26%) and the Faculty of Engineering (22%). The presence of respondents from faculties such as Humanities and Social Sciences (16%) and Natural Sciences (13%) ensures that the study captures diverse academic viewpoints.

Higher Education Levels: Faculties such as Medicine (83%) and Law (67%) had the highest percentage of participants with Master’s degrees or higher. This could imply that these fields may have more stringent educational requirements, which might influence their adoption and usage of advanced technologies like 5G.

- On Campus Connectivity

Overall over 85% of participants stated that they had either average or excellent experience using the wireless networks on campus encompassing both connectivity and speed. A mere 9% of participants stated that their experience was poor however some of these participants were attending universities in developed nations such as Germany, Spain, and Scotland highlighting the issue as not being one solely for developing nations.
Whilst we would expect since the early 2010’s when WiFi was standard at most universities from advanced nations some 30% of participants stated they have had issues with connectivity on campus, the majority of these participants were either students or alumni. The majority of University Professors, staff, and all of the university researchers stated they have never encountered issues with connectivity while on campus.

Of those who had stated they had connectivity issues some of the two most common challenges mentioned were poor connectivity and slow internet speed. Some respondents also mentioned issues with multi-factor authentication, coverage, and intermittent disconnections.

In order to improve the levels of technology adoption on campus participants top answer was implementing more smart/virtual classrooms. This coincides with the modern workplace adoption of working from home/hybrid working. The following areas were also among the highest areas selected; data analytics for student performance, personalized learning, and future career support, faster connectivity, and smart industry labs. The most unpopular areas for investment were around robotics and cyber security as most believe the current levels of security are sufficient for today’s needs.

Table 10. Understanding of 5G

<table>
<thead>
<tr>
<th>Level of Understanding</th>
<th>Administrative staff</th>
<th>Student</th>
<th>University alumni</th>
<th>University professor</th>
<th>University researcher</th>
<th>Grand Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extensive</td>
<td>3%</td>
<td>3%</td>
<td>4%</td>
<td>2%</td>
<td>1%</td>
<td>13%</td>
</tr>
<tr>
<td>Good</td>
<td>3%</td>
<td>9%</td>
<td>10%</td>
<td>2%</td>
<td>1%</td>
<td>25%</td>
</tr>
<tr>
<td>Neutral</td>
<td>1%</td>
<td>2%</td>
<td>7%</td>
<td>7%</td>
<td></td>
<td>17%</td>
</tr>
<tr>
<td>Limited</td>
<td>1%</td>
<td>3%</td>
<td>5%</td>
<td>5%</td>
<td>1%</td>
<td>15%</td>
</tr>
<tr>
<td>Nothing</td>
<td>2%</td>
<td>12%</td>
<td>13%</td>
<td>1%</td>
<td>2%</td>
<td>30%</td>
</tr>
</tbody>
</table>

The table above shows how well the participants understand 5G technology, which is the next generation of wireless communication that offers faster speed, lower latency, and higher capacity.
Low Awareness: A staggering 45% of participants reported either limited understanding or no understanding of 5G technology. This suggests a widespread lack of awareness about the capabilities and significance of 5G, which could hinder its adoption and utilization in various sectors, including education.

Limited Understanding: While some participants (17%) indicated a neutral understanding of 5G, only a medium percentage (38%) demonstrated an extensive or good level of understanding. This indicates a need for targeted educational initiatives to bridge the knowledge gap and empower individuals to leverage the potential of 5G effectively.

Clarifying Misconceptions: The survey also identified misconceptions among participants regarding the nature of 5G. For instance, some respondents associated 5G with satellite communication systems or smartphone storage, indicating a need for clarification and accurate information dissemination.

Focus on Possibilities: While participants generally associated 5G with technical terms such as connectivity, network, low latency, and speed, the survey highlights an opportunity to shift the narrative towards the transformative potential of 5G. Emphasizing the societal and economic benefits, such as enabling advanced healthcare services, autonomous transportation, and immersive educational experiences, can enhance engagement and appreciation of 5G technology.

Implications for Education: Given the prevalence of limited understanding among students, alumni, professors, and researchers, educational institutions have a crucial role to play in addressing the 5G knowledge gap. Integrating 5G-related content into curriculum and organizing workshops, seminars, and awareness campaigns can empower students and faculty to harness the full capabilities of 5G in research, teaching, and learning endeavors.

- 5G at Universities
To identify the priorities of the university community, participants were presented with a hypothetical scenario where they could allocate a generous donation of 1 Million EUR. This question aimed to provide a balanced choice, to understand the relative importance of 5G compared to other university priorities and potential investments.
Investment Preferences: A new scholarship for students wanting to study emerging technologies was overwhelmingly chosen as the favorite with over 44% of participants selecting this as their preferred option. As participants were able to select multiple answers the remaining results were each given close to 30% of the results each, with the second favorite between increasing staff salaries and hiring new professors, establishing a 5G research center to drive innovation and collaboration with industry partners, acquiring emerging and advanced technology devices and finally upgrading or modernizing the existing campus.

Participants were also able to propose their answers which themes varied between investing more in AI, international student experience, and specific forms of upgrades to the facilities or infrastructure of the campus.

- Belief in 5G Impact

Participants expressed high confidence in 5G's potential to achieve various objectives across university campuses. The majority believed that implementing 5G would significantly enhance innovative research, with over 75% of participants indicating a high or very high belief in its impact. Similarly, over 76% of participants stated a high or very high belief that 5G would support better data-driven decision-making.

Notably, participants identified efficient operations as the area where 5G could make the most significant difference, particularly through the deployment of smart solutions such as intelligent transportation and automated facilities. Only 8% of participants stated they had a low belief that 5G would have an impact on making the university more efficient.

Across different faculties and services, participants believed that research and innovation would greatly benefit from the introduction or enhancement of 5G, with all participants (100%) agreeing on this point. Computer science and engineering were also perceived to benefit significantly, with benefit scores of 87% and 62%, respectively. However, business faculties were perceived to receive comparatively lower benefits, with only 21% of participants stating a benefit for the finance area and 24% for human resources.
- Challenges and Concerns

Despite the perceived benefits, participants highlighted several challenges and concerns associated with implementing a Smart University Campus using 5G technology.

The most recurring theme centered on the cost and time required for a full rollout of 5G across the campus, with approximately 30% of participants expressing concerns about this aspect.

Some participants (approximately 30%) expressed concerns about the potential over-virtualization of the classroom experience and its impact on face-to-face learning, suggesting a desire to maintain a balance between virtual and traditional learning environments.

- 5G Industry Knowledge and Partnerships

The survey aimed to assess participants' awareness of the industry landscape for 5G technology and the potential benefits of collaborating with companies and government institutions to further develop and adopt this technology in educational settings.

5G Providers in the market: Only 14% of participants were aware of companies developing and deploying 5G technology in universities, indicating a low knowledge among the surveyed individuals. The majority were either unsure or had no idea about the companies involved.

Among the participants who were aware, there was unanimous recognition of the industry's major players, including Nokia, Huawei, Samsung, and Ericsson. This suggests a basic understanding of key stakeholders in the 5G ecosystem.

Benefits of Collaboration: Participants identified several benefits of collaborating with companies and government institutions to advance 5G technology in education. These included opportunities for student internships and experiential learning, access to industry expertise and resources, and bridging the gap between academia and workplace needs for Industry 4.0.
The analysis highlights the potential for collaboration with industry to enrich the academic curriculum and offer a more up-to-date learning experience for students. By integrating insights from industry partners, universities can ensure that their programs remain relevant and aligned with the latest advancements in 5G technology.

Opportunities for Industry 4.0 Innovation: Bringing the 5G industry landscape into universities can not only enhance students’ campus experience but also facilitate further research and innovation, providing new possibilities that were previously limited by outdated technologies.

Successful Collaborations: Participants cited the Arena 2036 project at Stuttgart University as a "gold standard" case in collaboration between universities and industries. This example serves as a benchmark for successful partnerships and underscores the potential for fruitful collaborations to drive innovation and advancement in 5G technology.

- Survey Conclusion

The survey findings reveal a significant gap in the perception and understanding of 5G technology among university stakeholders. Many respondents view wireless communication primarily as a means of internet connectivity, rather than an enabler of innovation and new possibilities. This limited perception underscores the need for educational institutions to enhance awareness and comprehension of 5G's capabilities. Despite this, there is a strong belief in 5G’s potential to enhance innovative research (75%) and data-driven decision-making (76%), highlighting its perceived value in academic advancement and operational efficiency. Additionally, the potential for 5G to optimize campus operations through smart solutions, such as intelligent transportation and automated facilities, suggests a vision for a highly efficient, tech-driven campus environment.

The findings also emphasize the importance of 5G providers increasing their presence and collaboration with universities, as there is currently low awareness of their existence and role. Participants identified several benefits of such collaborations, including student internships, experiential learning opportunities, access to industry expertise and resources, and bridging the gap between academia and workplace needs for Industry 4.0. By working
closely with industry partners, universities can enrich their academic curriculum, ensure programs remain relevant, and facilitate further research and innovation. This collaborative approach can enhance the educational experience, preparing students to thrive in a rapidly evolving technological landscape and fostering a future-ready educational environment.

3.3 Qualitative Data Analysis – Interviews

This section analyses the inputs gathered during the interviews conducted with the support of Finnish universities, and universities of applied science, participating in the 5G test Network Finland program:

1. Helsinki University
2. Aalto University
3. Tampere University
4. LUT University
5. Tampere Applied Science University
6. Saavonia Applied Science University
7. Lapin Applied Science University

In addition to the survey, six on-campus visits and observations were conducted. These visits allowed for firsthand witnessing of the technology deployed on university campuses, including 5G-enabled use cases and the partner ecosystems leveraged to run various projects across faculties. During these visits, discussions with students provided additional perspectives on the practical impacts of 5G technology on their educational experiences. This complementary approach enriched the basis of the research inquiry by providing a deeper, contextual understanding of the practical applications and impacts of 5G technology in an academic setting.

1. Tampere University
2. LUT University
3. Oulu University
4. Tampere Applied Science University
5. Saavonia Applied Science University
6. Lapin Applied Science University

After completing the interviews, measures were undertaken to ensure data accuracy and reliability. Video recordings were reviewed, and transcripts were generated and validated. Subsequently, a systematic coding process was employed to identify key themes and concepts within the interview transcripts.

Combining both predefined themes and emerging themes from the interview data. This approach ensures a comprehensive understanding of the impact of 5G on hyperconnected university campuses by considering both existing literature and new insights from interview participants and on-campus visits.

To enhance clarity and accessibility, a step-by-step data analysis process was applied to each interview conducted as follows:

Table 11. Step 1: Initial Code Development

<table>
<thead>
<tr>
<th>Predefined codes from research objectives</th>
</tr>
</thead>
<tbody>
<tr>
<td>- 5G and technology integration in the university campus</td>
</tr>
<tr>
<td>- User experience and impact</td>
</tr>
<tr>
<td>- Use Cases and Applications</td>
</tr>
<tr>
<td>- Industry partnership and Collaboration</td>
</tr>
<tr>
<td>- Challenges and Considerations</td>
</tr>
<tr>
<td>- Future Directions and Opportunities</td>
</tr>
<tr>
<td>- Student Involvement and Feedback</td>
</tr>
</tbody>
</table>

**Step 2:** Data Collection and Preparation

- Interviews were conducted with various stakeholders, including professors, administrative staff, students, and industry experts.
- Transcripts were validated for accuracy.

**Step 3:** Initial Coding

- Predefined themes were applied to the interview transcripts.
- Example: A statement like "5G technology has significantly improved our IoT project development" would be coded under User Experience and Impact (Green).

**Step 4: Emergent Coding**

- New themes that emerged from the data were identified and coded.
- Example: Recurring mentions of "collaborative learning" emerged as a new theme and were coded accordingly.

**Step 5: Iterative Review and Refinement**

- Transcripts were reviewed iteratively to ensure all instances of emergent themes were captured.
- Adjustments to existing codes were made based on new insights.

**Step 6: Thematic Analysis**

Related codes were grouped into broader themes to draw more comprehensive conclusions. Example: Technology Integration and Collaborative Learning were grouped under a broader theme like Educational Enhancements.

**Step 7: Reporting Findings**

The following sections outline the key findings of the interviews and the subsequent coding of their data, these are presented in the consequently tables with supporting quotes and a summary of key insights.

Table 12. Interview findings Helsinki University

<table>
<thead>
<tr>
<th>Theme</th>
<th>Key Insights</th>
<th>Supporting Quotes</th>
</tr>
</thead>
<tbody>
<tr>
<td>5G and technology integration</td>
<td>- Early stages of deployment.</td>
<td>&quot;We have pland for the network deployment but we are still on the legal review&quot;.</td>
</tr>
<tr>
<td></td>
<td>- Ongoing &quot;Smart Campus&quot; initiative.</td>
<td>&quot;Plans to developing something called the Smart Campus idea.&quot;</td>
</tr>
<tr>
<td>User Experience and Impact</td>
<td>- Anticipated enhancement of remote and hybrid teaching</td>
<td>&quot;We have been developing... to help remote and hybrid teaching and learning.&quot;</td>
</tr>
<tr>
<td></td>
<td>- Limited current impact</td>
<td>&quot;We find out something that the university wants to do and</td>
</tr>
</tbody>
</table>
then try to find whether the testbed could be used for something."

"Educational use case is always something we look for across different areas. "Students could use the test network for their thesis."

"Multidisciplinary team... sharing challenges from different faculties." 
"We need a plan to become a smart campus."

"We don't have a concrete plan on that unfortunately."  
"Funding for the project is one thing."

"Trying to build it in such a way that the students and researchers could take the thing forward."

"Students could use the test network for their thesis." –  
"We have been developing... to help remote and hybrid teaching and learning."

<table>
<thead>
<tr>
<th>Theme</th>
<th>Insights</th>
<th>Supporting Quotes</th>
</tr>
</thead>
</table>
| 5G and technology integration | - Aalto University has acquired spectrum licenses for 3.5 GHz and 26.4 GHz bands, allowing for 5G deployment.  
- Both outdoor and indoor base stations are being installed across the campus to facilitate various use cases. | "We got a frequency license...on 26400 megahertz."  
"We have installed around 11 base stations of millimeter wave."                                      |
<table>
<thead>
<tr>
<th>Challenges and Considerations</th>
<th>“There was not a single network in the whole Finland that was configured with the standalone, plus there were very low 5G devices.”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Use Cases and Applications</td>
<td>“We have been testing self-driving vehicles across the campus.” &quot;For example, can we use edge computing with like a low power computing systems close to the source of the data.&quot; &quot;We are looking at how we can reduce the energy consumption from the communication point of view.”</td>
</tr>
<tr>
<td>Industry partnership and Collaboration</td>
<td>“We connected all the different universities...to interconnect all these entities and build this network together.&quot; &quot;We get access to equipment, software, and some level of support with Nokia, also for 5G curriculum development.”</td>
</tr>
<tr>
<td>Future Directions and Opportunities</td>
<td>&quot;Some people come from different fields, they get interested to land on the</td>
</tr>
</tbody>
</table>
Table 14. Interview Findings Tampere University

<table>
<thead>
<tr>
<th>Theme</th>
<th>Insights</th>
<th>Supporting Quotes</th>
</tr>
</thead>
</table>
| 5G and technology integration | - Tampere University has been involved in wireless communication research since the early 2000s, starting with 3G networks and progressing through 4G and into the early stages of 5G by 2019.  
- While current usage is heavily technology-focused, there is a clear drive to promote cross-disciplinary collaboration, facilitating the use of these technologies in diverse fields such as health sciences, business, and beyond. The university is also enhancing its infrastructure to support broader applications, aiming to create a more interconnected and technologically advanced world. | "Tampere University has been partnering with Nokia for a long time, every wireless generation has been part of our studies since the 2000s."  
"There is an ongoing effort to increase awareness and integration of advanced technologies like 5G across different faculties and disciplines." |
| Use Cases and Applications    | - The university is globally recognized for its high-quality research and publications in wireless communications, with a significant focus on advancing and testing new network technologies.  
- The practical applications of 5G at Tampere University extend to various fields. Specific examples include early adoption and integration in healthcare, business, and beyond. | "Reputation is supported by a dedicated team continuously working on network evolution, demonstrating the university's strong emphasis on integrating cutting-edge research with educational programs." |
<table>
<thead>
<tr>
<th><strong>User Experience and Impact</strong></th>
<th>The establishment and continuous upgrade of test networks, including dedicated RF Laboratories and equipment, allow for extensive experimentation and development.</th>
<th>“Wireless facilities are crucial for enabling students and researchers to study, innovate, and test new technologies beyond theoretical research.”</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Industry partnership and Collaboration</strong></td>
<td>A longstanding collaboration with Nokia and other companies has been a cornerstone of Tampere University's success in telecommunications research. This partnership has facilitated numerous projects, benefiting both the university's research capabilities and the industry's technological advancements.</td>
<td>“5G relationship with Nokia is mutually beneficial, fostering continuous innovation and application of new technologies.”</td>
</tr>
<tr>
<td><strong>Future Directions and Opportunities</strong></td>
<td>By incorporating advanced technologies into educational programs and providing hands-on experience with cutting-edge infrastructure, the university aims to equip students with the necessary competencies to thrive in growing markets.</td>
<td>“Tampere University is focused on preparing students with the skills required for future demands, particularly in industries that are becoming increasingly technologically advanced.”</td>
</tr>
</tbody>
</table>
technologically advanced environments.

increasingly automated and digitized”

Table 15. Interview Findings LUT University

<table>
<thead>
<tr>
<th>Theme</th>
<th>Insights</th>
<th>Supporting Quotes</th>
</tr>
</thead>
<tbody>
<tr>
<td>5G and technology integration</td>
<td>LUT began working on a 5G test network in 2018. New projects aiming to have the network operational by May 2024.</td>
<td>&quot;We have made an initial deployment in 2018, now a new deployment is schedule of the installation of the 5G test network here during this spring so it should be up and running by the end of May.&quot;</td>
</tr>
<tr>
<td>Challenges and Concernes</td>
<td>The development of the 5G network faced delays due to funding issues, personnel changes, and global supply chain problems.</td>
<td>&quot;There were some challenges and delays in delivery and getting all the components... the last package was in the end of January.&quot; -&quot;Unfortunately then they decided that we need to cut some projects...</td>
</tr>
<tr>
<td>Use Cases and Applications</td>
<td>-Initial use cases focused on energy management, such as demand response and data collection from sensors around the campus. Future plans include mapping more use</td>
<td>&quot;We are planning to replicate with 5G some use cases focused on energy (SGEMM-FlexE). There</td>
</tr>
</tbody>
</table>
| Industry partnership and Collaboration | cases, particularly in building automation and e-mobility. 
- Thesis Work and Research 
Past projects include SGEMM (Smart Grids and Energy Markets) and FlexE (System Flexibility), which aimed to address data traffic and system control issues. 
- VR/XR LUT is integrating its 5G network with the newly established E-mobility Research Center in collaboration with industrial partners like Kem Power |
| | are thesis workers focus on 5G applications." 
"Last year we had in LUTES the VR project Mökki enabled with the 5G network and has been expanded to Africa” 
"Our intention is also to have the 5G test network in Lahti to serve the E-mobility Research Center." |
| Industry partnership and Collaboration | - Fostering closer communication and collaboration between industry and academia to create win-win situations and drive concrete projects. 
- LUT University has had a history of collaboration with Nokia. These collaborations have often focused on smart grids and energy systems. 
Proposing collaboration between university projects and industrial partners, specifically in 5G and IoT applications 
- Mentioning international projects, from the use cases can revolutionize education through connected immersive spaces requiring strong connectivity |
| | "I see clearly that it would be just win win for both sides Nokia and LUT if we could somehow give at least being in close communications" 
We had Nokia Siemens networks involved... we are working heavily on energy and its sector and segment." 
- "if there is such a requirement in terms of like IoT’s application software and so on, how we can connect that to reality" 
- "We have this initiative of like sort of revolutionized the education and university education particularly in utilizing
seamlessly connected immersive test spaces

<table>
<thead>
<tr>
<th>Theme</th>
<th>Insights</th>
<th>Supporting Quotes</th>
</tr>
</thead>
</table>
| 5G and technology integration| - Challenges regarding technology integration and application  
                        - Integrating technology across various fields, including healthcare and manufacturing, is essential for future advancements. Ensuring that stakeholders across different sectors understand the relevance and potential of technologies like 5G can drive investment, innovation, and collaboration. | “TAMK has deployed the 5G test Network, but we have quite a few challenges”  
                        “Everything right now has technology involvement. It's not just about siloed tech fields; it's about integration. If even management doesn't understand technology, there won't be enough motivation or drive. Operators are also moving towards 5G for industries, not just end consumers.” |
<p>| Use cases and applications   | Different individuals have varied learning preferences, with some being more visually oriented, while others prefer hands-on experiences. Creating educational environments that cater to these diverse learning styles can enhance comprehension and engagement. | “Everybody is different in terms of how they learn. Some are more focused on what they see, others on what they can touch. If I teach about 4G or 5G systems, I want to show how they work. If we have a test bed, I can |</p>
<table>
<thead>
<tr>
<th>Challenges and Concerns</th>
<th>The education sector, takes longer on integrating technology for daily operations, teaching or experimentation. Establishing robust partnerships between universities, companies, and governments is crucial for creating cutting-edge educational ecosystems.</th>
<th>&quot;The education sector takes more time for high technology adoption. If we had better collaboration with companies and governments, along with student involvement in projects, it could be more beneficial. We need more support in creating an ecosystem where we can showcase and experiment with the latest technologies.&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Network Awareness</td>
<td>Awareness about available networks, like private 5G systems in educational institutions, among stakeholders is crucial for maximizing utilization. Lack of awareness can hinder collaboration and limit the potential benefits of the network. Clear communication and promotion of available resources are necessary to ensure widespread adoption and usage.</td>
<td>&quot;If it works, we promote it. If not, we keep quiet. But awareness is key. Even management needs to know about available networks. Lack of awareness among stakeholders limits collaboration and innovation. Students know we have a private 5G system, but not everyone is aware. We need better communication and promotion of available resources.&quot;</td>
</tr>
</tbody>
</table>
Industry partnership and Collaboration

Collaborating with industries aligned with the country's economic focus can lead to mutually beneficial initiatives. Understanding the local economic landscape and technological needs of industries helps in tailoring educational programs and research projects to address real-world challenges and foster innovation.

"Let's pick industries that are beneficial for Finland's economy, like forestry. We can collaborate with companies in these sectors to develop use cases and address their challenges. Labs don't need to be topic-specific; they should align with local industries. Understanding local economic focus is key." Collaboration is crucial for driving innovation across diverse fields.

<table>
<thead>
<tr>
<th>Theme</th>
<th>Insights</th>
<th>Supporting Quotes</th>
</tr>
</thead>
<tbody>
<tr>
<td>5G and technology integration</td>
<td>The motivation for deploying the 5G testbed was to facilitate fast data transfer and intelligent systems within the university. The network has been stable with early warning systems for issues.</td>
<td>&quot;The aim was to have this kind of fast data transfer and intelligent systems and high tech application across different fields.&quot;</td>
</tr>
</tbody>
</table>
| Awareness and Interest                             | -Management and professors have mixed levels of awareness and interest in 5G, with some actively exploring its benefits while others are less informed.  
-Some professors are engaged in leveraging 5G for advanced | "There are both ends so that some people are very aware... we have to utilize this digital technology in all the fields that's possible."  
"We have this master degree in digital health" |
applications, though there is potential for more interdisciplinary collaboration.

- Students, especially in applied sciences, are more aware of 5G through practical projects and applications.

program... how this technology could be used for example in nursing care."

"We are applied science university... research is also something applied actually." -

Use cases and applications

5G is being integrated into various educational aspects such as hybrid classrooms, practical labs, and applied research.

Practical labs and research projects help students understand real-world applications of 5G technology.

Emphasis on applied research aligns with the university’s focus on preparing students for industry demands.

Savonia offers programs like Digital Health and IoT Engineering, which benefit from 5G’s high data transfer rates, low latency, and massive communication capabilities.

The university is exploring various applications for 5G, including augmented and virtual reality, smart factories, and data-driven manufacturing.

Smart campus initiatives, including smart logistics, security, and building automation and robotics can benefit from 5G technology.

"We have students in the class here and some students from different parts... connecting us via Zoom or Teams."

"We are focusing on high-definition IoT... these kinds of things are happening and probably this will help in our students also"

"We are doing something which is very quickly applied to the society."

"We try to include this 5G in experiments like augmented or virtual reality, also we have in the university a smart factory, smart water lab, remote machinery for mechanical engineering and e-health master"

"We have been working on secure data communication"
| Student Involvement and Projects | Students are actively involved in projects using 5G, providing them with hands-on experience and contributing to real-world applications like autonomous robots and smart factories. | "We have created different digital twins and students are working on these projects to optimize resources and improve systems." |
| Industry partnership and Collaboration | Collaboration with external partners and across departments is crucial for converting research into marketable innovations, supported by initiatives like the business center. | "Without collaborations with companies or projects, it's not possible to bring novel and innovative things to the market."

“Projects funded by entities like Business Finland and involving partners like Nokia focus on AI, high data rate computation, and cyber security in the context of 5G”. |
| Future Vision | Future developments in 5G technology will continue to enhance its applicability in education, especially in areas like high-speed data streaming, mobility and students preparedness

Collaboration between academia and industry is crucial for advancing the application of 5G technologies in education and beyond | "We are the generation so that we can see one day in 10 years or five years probably I would say." - When the skills that I need to learn right now in the university are the skills that I can just replicate in the future... academia and industry need to come and work together." |
Exploring 5G use cases in healthcare can improve patient care, hospital operations, and building automation, providing valuable learning opportunities.

<table>
<thead>
<tr>
<th>Theme</th>
<th>Insights</th>
<th>Supporting Quotes</th>
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<tbody>
<tr>
<td>5G and technology integration</td>
<td>The university decided to set up its own 5G testbed with Nokia, avoiding reliance on external operators for flexibility and control. The installation process was relatively quick, taking about 2-3 months, despite the team having limited prior experience with 5G technology. The motivation for deploying 5G was a general awareness of its future potential, with funding challenges overcome through securing project-based funding.</td>
<td>&quot;We decided to have our own and our mastered system... control plane is running in Nokia data center and user plane is here at our site.&quot; - &quot;It took about maybe two to three months to get it working... we didn't have any experience before. &quot;We don't have a university's own money to make to work with the installation... we were lucky to have that one project and we could use that fund to make installation.&quot;</td>
</tr>
<tr>
<td>Challenges and concerns</td>
<td>Initial challenges included lack of documentation and difficulty using the Nokia portal for information.</td>
<td>&quot;We couldn't find the information from the Nokia portal... I want to increase power over outdoor radio and plus antenna... it's very hard to find.&quot;</td>
</tr>
</tbody>
</table>
| Use cases and applications | The 5G network is used primarily for engineering education, but there are ongoing projects like forestry and autonomous systems benefiting from 5G. | "We are providing the network for the cameras and infrared sensors or different equipments on the area, there's drones running, digital twin and intelligent traffic road, autonomous vehicles projects"

| Industry partnership and Collaboration | The university collaborates with other universities and partners in Europe, using 5G to facilitate various research and development projects. | "Partners are more universities, but within this EU project, there is a European universities, research institutes, companies... very different fields."

| Future Vision | The university is in the early stages of 5G implementation and has 5G-enabled innovation centers, also sees potential in future developments. | "We are so starting phase yet... right now the university has a Innovation Center enabled by 5G also we have use cases, projects, professors and the technology to keep developing more use cases"

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**Interviews Conclusion**

The analysis of interviews from seven universities and universities of applied science in Finland, reveals that a 5G hyper-connected campus could enhance the education experience by facilitating advanced learning environments, practical applications, and innovative use cases. Key themes highlight the role of 5G in enabling high-speed, low-latency connections that support smart classrooms and remote learning, enhancing educational flexibility and accessibility. Students gain hands-on experience in research projects using 5G technology, preparing them for industry demands and the future workplace.
Furthermore, universities are exploring diverse applications of 5G, including autonomous vehicles, smart factories, and augmented/virtual reality, which contribute to a rich, innovative educational environment.

In terms of specific 5G-enabled use cases, universities are leveraging the technology for projects across different engineering fields, like automation, drones, and sustainable technologies. These include network testing, smart grids, energy and water management, and environmental monitoring, all of which promote sustainability and efficiency. Case studies like the "Mökki" project in Finland demonstrate the global scalability of successful 5G initiatives. Additionally, cross-disciplinary collaborations enhance research output, reflecting the positive impact of 5G on academic and research activities. These initiatives not only boost the quality of research but also elevate the university's reputation and contribute to global knowledge-sharing and innovation.

The implementation of 5G in universities requires a robust partner ecosystem, involving industry collaborations, government support, and strategic planning. Partnerships with tech companies provide crucial technical expertise and resources, while government involvement ensures necessary funding and strategic initiatives. However, challenges such as funding issues, technical difficulties, and a lack of 5G awareness among faculty and staff need to be addressed. Despite these challenges, the integration of 5G technology prepares students for future technological landscapes, bridging the gap between academic knowledge and industry demands, and fostering dynamic, innovative campuses that serve as hubs for co-creation and practical learning.
4 Findings

The following sections outline the key findings of the research methods. Through comprehensive data gathering and analysis involving literature reviews, surveys, interviews, and direct observations several key themes and insights have emerged that contribute to answering the main research question: "How does a 5G hyper-connected university campus enhance the education experience?" These themes also address the sub-questions regarding 5G-enabled use cases, university case studies, and the necessary partner ecosystem for 5G implementation,

Main Research Question: How does 5G hyper-connected university campus enhance the education experience?

- Enhanced Learning Environments: smart classrooms equipped with interactive whiteboards, VR headsets, and AR systems facilitate hybrid teaching models, enabling in-person and remote learning. Connected libraries as digital hubs offer real-time access to vast resources and collaborative tools. 5G also enables virtual labs and AR experiences, providing hands-on learning opportunities in virtual settings, to enable these environments key devices are needed including, IoT sensors, high-performance computing infrastructure, and robust networking equipment.

- Enhanced campus facilities and Hands-On experiential learning: students and professors highlight the value of actively engaging in R&D projects using 5G technology, gaining experience that prepares them for industry demands. Some universities have developed smart facilities that offer students hands-on learning opportunities but also serve as practical spaces for professors to showcase cutting-edge technologies and real industry examples. Professors can innovate their teaching methods, making lectures more dynamic and relevant. Additionally, industries benefit from collaborating with students and professors on advanced use cases, gaining fresh insights, and exploring how to integrate these advancements into their own operations.
- **Enhanced Collaboration and Innovation**: 5G supports collaborative research by connecting various departments and facilitating the sharing of large data sets and resources. This encourages interdisciplinary projects and innovation, enhancing the university's research output and reputation.

- **Overcoming Traditional Wi-Fi Limitations**: unlike traditional Wi-Fi, which struggles with coverage and reliability in large and complex environments, 5G provides robust and extensive coverage across the entire campus. This ensures that all areas, including outdoor spaces, are connected, supporting continuous learning and operations.

- **Prepared Workforce and skilled students**: by providing students with access to the latest technologies and practical applications, 5G-equipped campuses prepare graduates to meet the demands of Industry 4.0. This includes skills in automation, IoT, and data analytics, ensuring that students are workforce-ready and can contribute effectively to their chosen fields. Enhanced Infrastructure for Students, Professors, and Sustainable Practices:

- **Overall Infrastructure Improvement**: 5G supports the development of an advanced infrastructure that benefits students, professors, and the campus infrastructure. Enhanced connectivity, efficient resource management, and sustainable practices create a more conducive learning and teaching environment, enabling academic excellence and innovation.

Sub-Question 1: *What are the 5G-enabled use cases and case studies on the university campus?*

The following table presents various 5G-enabled use cases, with some already in testing or deployment phases, while others are speculative but grounded in current research and industry trends. These use cases are derived from multiple sources, including the literature review (specifically section 2.10 on 5G Case Studies and Use Cases on University Campuses), direct observations, discussions with professors, staff, and students part of the 5G testbed network in Finland, as well as the author’s professional experience working with 5G technology for Industry 4.0 at Nokia.
In the context of Industry 4.0 and 5G, use cases refer to practical applications of the technology that can transform educational environments and processes. The development of these use cases is led by subject matter experts, including professors and industry professionals, ensuring they are both technologically sound and pedagogically relevant. Given the survey results indicating a limited understanding of 5G, it is crucial to emphasize that these proposed use cases are rooted in expert knowledge and practical insights.

Table 19. 5G-Enabled Use Cases in University Campuses

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<thead>
<tr>
<th>Category</th>
<th>Concept</th>
<th>Use Cases</th>
<th>Phase</th>
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| Smart Infrastructure| Implementing intelligent and connected physical infrastructure to support the needs of a modern educational institution | - **IoT-enabled building management systems**: Continuous monitoring of energy usage, HVAC regulation, and anticipatory maintenance.  
- **Smart lighting**: Adaptive lighting based on occupancy and daylight levels.  
- **Energy-efficient solutions**: Optimizing energy usage across campus buildings.  
- **Automated maintenance systems**: Proactive maintenance using sensors and data analytics  
- **Smart sports arena**: Enhanced fan experiences through AR/VR, real-time stats, and interactive displays. | - Testing |
| Smart Classrooms and Learning Spaces | Creating technologically enhanced classrooms and learning spaces | - **Interactive whiteboards:** Collaborative learning and dynamic presentations.  
- **Smart projectors:** Augmented content delivery.  
- **IoT devices:** Real-time data collection for research and teaching.  
- **VR/AR:** Immersive learning experiences.  
- **Advanced cameras:** Lecture capture and behavioral analysis.  
- **Sensor-enabled behavioral analytics:** Monitoring student engagement and well-being.  
- **Smart lighting:** Adaptive illumination for optimal focus. | - *Testing and Development* |
| Industry 4.0 Learning Campus | Transforming traditional learning environments into immersive experiences | - **Automated logistics:** Efficient supply chain management.  
- **Remote control:** Simulating industrial processes.  
- **Predictive analytics:** Anticipating maintenance needs.  
- **Smart energy management:** Optimizing energy usage in labs and workshops.  
- **Connected worker:** Wearable devices for safety and productivity.  
- **VR/AR:** Training for manufacturing and assembly.  
- **Robotic surgery and e-health:** Medical training and telemedicine.  
- **Drones inspection:** Precision farming research, and monitoring in agriculture  
- Partnerships with industry leaders for real-world projects. | - *Deployment* |
| IoT-based Campus Management | Enhancing campus operations, security, and resource management | - **Smart parking systems**: Real-time availability tracking.  
- **Environmental monitoring**: Air quality, noise levels, and waste management.  
- **Connected security systems**: Surveillance, access control, and emergency response.  
- **IoT-enabled maintenance**: Predictive maintenance for facilities and equipment. | - Development and Testing |
|----------------------------|---------------------------------------------------------------|-----------------------------------------------------------------|----------------------------------|
| Smart Libraries and Resource Centers | Transforming libraries into dynamic, digital resource hubs | - **Digital catalogs**: Easy access to library materials.  
- **RFID technology for book tracking**: Efficient inventory management.  
- **Online databases**: Access to scholarly articles and research.  
- **Interactive learning resources**: Virtual labs, simulations, and e-books. | - Deployment |
| Digital Signage and Information Systems | Enhancing communication across the campus | - **Interactive kiosks**: Wayfinding, event information, and campus services.  
- **Digital displays**: Announcements, news, and emergency alerts.  
- **Campus-wide communication platforms**: Centralized updates for students and staff. | - Deployment |
| Safety and Access Control | Strengthening campus security | - **Biometric scanners**: Secure access to buildings and labs.  
- **Facial recognition technology**: Enhanced identity verification.  
- **Secure access control systems**: Restricted area management.  
- **Video analytics**: enhanced asset management, tracking valuable equipment. | - Development and Testing |
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<tr>
<th>Augmented Reality (AR) Campus Tours</th>
<th>Offering interactive and immersive campus tours</th>
<th>- <strong>AR applications/devices:</strong> Virtual overlays with historical context, building information, and campus highlights.</th>
<th>- Development</th>
</tr>
</thead>
</table>
| Smart Campus Sustainability         | Reducing environmental impact                  | - **Energy-efficient buildings:** Smart HVAC, lighting, and insulation.  
- **Waste reduction programs:** Recycling initiatives and waste sorting.  
- **Renewable energy sources:** Solar panels and wind turbines.  
- **Additional sensors on Smart Poles:** Monitoring CO2 emissions and air quality. | - Testing and Deployment |
| Student Information Systems (SIS) and Cloud Computing for Education | Efficient student management                   | - **Integrated Student Information Systems:** Enrollment, grades, and course registration.  
- **Cloud-based databases:** Secure storage and accessibility.  
- **Analytics tools:** Data-driven insights for academic planning. | - Deployment |
| Emergency Response Systems         | Ensuring safety during crises                  | - **Integrated alert systems:** Instant notifications for emergencies.  
- **Geolocation tracking:** Locating students and staff during evacuations.  
- **Communication tools:** Coordinating responses and providing instructions.  
- **Drones:** rescue and emergency first response | - Development and Testing |

While many use cases might seem feasible with 3G or 4G technologies, 5G offers unique capabilities such as ultra-low latency, higher bandwidth, and greater connectivity density. This enables a more comprehensive and integrated approach, allowing a single technology
to support a wide range of applications across the entire campus, rather than relying on multiple networks.

Sub-Question 2: What are universities' case studies with 5G technology, and how do they perceive its impact on stakeholders?

Numerous universities mainly in Europe and The United States are leveraging 5G technology to enhance education and research across disciplines such as engineering and health sciences. However, the adoption of 5G in universities remains relatively low due to funding limitations, technical challenges, and a lack of awareness among faculties.

The following case studies are highlighted due to their commonalities: each involves a major telecommunication provider like Nokia or Samsung, focuses on 5G for innovation and research, emphasizes industrial applications, and features well-defined projects with a very well-defined industrial partnerships ecosystem.

- **5G Test Network Finland**

The 5G Test Network Finland (5GTNF) is a collaborative program for advancing telecommunications, particularly for R&D. Through collaborations with several universities in Finland, research institutes, like VTT and industry leaders like Nokia, 5GTNF provided a cutting-edge test platform for research, development, trials, and demonstrations, facilitated by a broad ecosystem shown in appendix 6. 5GTNF fosters innovation and strengthens industry-academia partnerships by facilitating the development and testing of 5G-enabled solutions (5GTN 2023).
The University of Oulu in Finland stands at the forefront of 5G research, forging impactful collaborations with industries to demonstrate the tangible advantages of this cutting-edge technology. Among its pioneering initiatives are projects focusing on smart health applications, industrial automation, and intelligent transportation systems. Notably, the university maintains a robust partnership with Nokia in the realm of radio and telecommunication, further solidifying its position as a key player in advancing wireless systems.

- **Stuttgart University: Arena 2036**

Stuttgart University's Arena 2036 project in Germany focuses on the future of mobility and manufacturing, utilizing 5G to enhance automation and real-time data exchange. This research campus allows experimentation with new manufacturing technologies and processes, demonstrating 5G's impact on operational efficiencies and industry-academia collaboration.

- **University of Surrey: 5G Innovation Centre**
The University of Surrey in the UK hosts the 5G Innovation Centre (5GIC), a leading research hub for 5G applications and services. Collaborating with industry giants, 5GIC focuses on smart cities, autonomous vehicles, and remote healthcare. The centre's work showcases 5G's transformative potential in both academic research and practical applications.

- University of Technology Sydney: 5G Innovation Lab

The University of Technology Sydney (UTS) has a 5G Innovation Lab that explores smart infrastructure, IoT, and digital health. The lab provides a testing environment for innovative 5G projects, enhancing educational experiences and industry collaboration. UTS's initiatives highlight 5G's potential to revolutionize research and practical applications.

- Aalborg University: 5G Smart Lab for Robotics

Aalborg University in Denmark hosts the 5G Smart Lab, focusing on robotics and automation. The lab uses 5G for real-time control and communication in collaborative robots, autonomous systems, and smart manufacturing solutions. Aalborg's work demonstrates 5G's impact on advancing robotics research and industrial applications.

Sub-Question 3: What is the partner ecosystem required to ramp up 5G technology in the university context?

- Industry Partnerships and Collaboration: In the quest to advance 5G technology within university contexts, strategic partnerships with industry leaders become indispensable. For instance, in the Faculty of Medicine, collaborations with companies like General Electric or Philips are crucial to bring in state-of-the-art medical equipment that could be integrated with 5G capabilities, facilitating the development of innovative healthcare solutions. Similarly, in the Industrial Engineering department, partnerships with autonomous mobile robot manufacturers enable the testing of automated logistics systems powered by 5G connectivity.
In these partnerships, both universities and industries derive mutual benefits; universities gain access to cutting-edge technologies that students will encounter in their future careers, while industries gain insights from academia's research expertise.

- **Government and Academic Collaboration:** The involvement of governmental bodies is vital in the context of 5G technology deployment in universities. Beyond providing financial backing, government support ensures strategic alignment and regulatory frameworks conducive to 5G adoption (spectrum availability).

Collaborative efforts between government entities and academic institutions facilitate the establishment of guidelines, policies, and standards that streamline the integration of 5G into university infrastructures. Moreover, government-academic partnerships foster research initiatives and enable access to funding opportunities tailored specifically to 5G research and development endeavors. This collaboration enables universities to be aligned with broader national agendas for technological progress.

The implementation of 5G infrastructure underscores the importance of robust partnerships, essential for securing funding and optimizing its utilization. Collaborations with telecommunications providers and governmental bodies are crucial for acquiring resources and regulatory support necessary for establishing the foundational infrastructure. Additionally, partnerships with industry players are vital for integrating advanced IoT technologies, and driving research and development efforts. Without such alliances, the deployment of 5G may remain underutilized, lacking transformative applications. Therefore, fostering strategic partnerships across sectors is imperative for fully realizing the potential of 5G, ensuring its effective integration into various domains, and facilitating meaningful advancements in the technological landscape.

**Emerged themes**

- **Challenges and Concerns**
Findings from both interviews and survey responses shed light on the multifaceted challenges and concerns inherent in the deployment of 5G technology within university contexts.

Initial interviews revealed a spectrum of challenges, ranging from the lack of documentation and difficulty in navigating the telecommunication provider portal for information to varying levels of awareness and interest among management and professors. While some educators actively explored the potential benefits of 5G, others exhibited less familiarity with its applications. Additionally, there was noted potential for increased interdisciplinary collaboration, particularly among professors engaged in leveraging 5G for advanced applications. However, the slow integration of technology into daily operations and teaching methodologies within the education sector was acknowledged, underscoring the importance of establishing robust partnerships between universities, industry, and governments to foster cutting-edge educational ecosystems.

Parallel to these insights, the survey responses underscored several persistent challenges. Foremost among these was the considerable cost and time associated with a full campus-wide rollout of 5G. Concurrently, an equivalent percentage of respondents voiced apprehensions regarding the potential over-virtualization of the classroom experience, emphasizing the importance of maintaining a balanced approach between virtual and traditional learning environments. However, perhaps the most pressing challenge identified through the survey was the widespread lack of awareness about 5G technology among faculty and staff.

Integrating these insights with the previously identified challenges, it becomes evident that addressing funding constraints, navigating technical complexities, and achieving a harmonious balance between virtual and traditional learning environments are crucial components of successfully deploying 5G technology in universities. However, the overarching challenge of overcoming low awareness emerges as the most prominent barrier, highlighting the imperative for targeted educational efforts to understand better the potential of 5G in transforming educational experiences.
- **Student Future Preparedness**

A key benefit of integrating 5G technology into university campuses is the preparation that offers to students for future technological and industry 4.0 landscapes across all sectors. By leveraging government and industrial partnerships, universities can create dynamic campuses that serve as hubs for innovation, co-creation, and practical learning, this helps to bridge the gap between academic knowledge and industry reality.

The findings underscore the educational enhancements, use cases, and partner ecosystem necessary to leverage 5G technology on university campuses. Inspired by these insights, the author developed a 5G hyper-connected university campus conceptual model, providing a visualization of an advanced, dynamic campus in contrast to a traditional one with a low degree of technology integration. Furthermore, the author proposed a 5G University Campus impact model that reflects the helix partner ecosystem required, the 5G capabilities inside of the university campus, and its value realization in society.

### 4.1 5G Hyperconnected University Campus Conceptual Model

The conceptual model for the 5G Hyperconnected University Campus is based on thorough research and systematic analysis conducted for this thesis. It is built upon the findings gathered through various research methods, including observation, survey, interviews, case studies, and literature reviews. These methods provided a comprehensive understanding of the challenges, needs, and potential applications of 5G technology in a university setting. As 5G deployment accelerates across multiple industries, realizing significant benefits and advancing Industry 4.0 (Merklinger 2023) as shown in the following figure, the conceptual model reflects these developments while addressing the opportunities of 5G integration across various academic fields.
The conceptual model integrates these industry advancements within the academic setting proposing a hyperconnected university campus that mirrors societal development. This model envisions a smart university campus as a central hub for innovation and entrepreneurship, blending theoretical knowledge with practical applications. By co-locating various industries within the campus, the model fosters an open ecosystem for interdisciplinary collaboration and hands-on practice, preparing students for the demands of the modern workforce.
1. **Smart University Campus:** this category integrates advanced technologies to enhance the learning experiences of students and faculty. It includes smart classrooms, libraries, and learning environments, automated administrative processes, smart building applications like energy-efficient buildings, and intelligent transportation systems.

2. **Industry 4.0 Learning Campus:** It proposed a change to the traditional learning environments into immersive experiences aligned with industry 4.0 demands. It includes simulated smart factories, precision agriculture fields, virtual construction sites, smart grid systems, and smart hospitals, providing hands-on training and research opportunities.

3. **Sustainable Living and Mobility:** This category emphasizes environmental sustainability, smart student resident building, smart arena, and transportation systems testing ground. It includes renewable energy sources, waste management systems, electric vehicle infrastructure, health monitoring and tracking, sports performance, immersive event experience, fully automated 24/7 convenience store, and green spaces, promoting sustainable living and mobility solutions like driverless car, and drones.

4. **Entrepreneurship Hub:** This dynamic ecosystem enables innovation and collaboration between students, academic institutions, and industry partners. It provides resources and support for aspiring entrepreneurs, serving as a convergence point for advanced technology projects and real-world challenges.

4.1.1 Conceptual Model Development Process

**Abstract Representation:** A conceptual model is an abstract representation that outlines the key components and relationships within a system. It serves as a blueprint or framework that guides the development and implementation of actual prototypes or pilots (Stanford Institute for Higher Education Research 2023). In this case, the conceptual model includes the co-location of various industries within the campus, the integration of smart city and Industry 4.0 principles, and the identification of primary use cases. It is not a physical implementation but a detailed plan that can be used to guide future developments.
Focus on Theory and Practice: The conceptual model envisions a smart university campus that serves as a hub for innovation and entrepreneurship, blending academic theory with hands-on practice. This model provides a comprehensive vision that can inspire and guide the higher education community in developing and implementing 5G technologies in a structured and effective manner.

Reproducibility and Applicability: The main objective of the model is to visualize the possibilities and opportunities that 5G can bring to the university campus. Based on industry applications, universities can adapt it according to their specific needs, budget availability, focused research areas, and local economic interests, enabling 5G for the use cases most relevant to them. It is not limited to a single pilot or model but provides a generalized framework that can be adapted and applied to various university settings, this reproducibility ensures that the model can be evaluated and validated through scientific methods, rather than relying solely on subjective judgment.

Structured Development Process: The development of the conceptual model followed a structured process, including:

- Identifying Application Areas: Development of categories and use cases that match the university context and mirror the current industry outlook.
- Synthesizing Data: Combining data primarily from six on-campus visits, literature reviews, and interviews to create a coherent vision.
- Applying Frameworks: Utilizing established frameworks such as smart cities and Industry 4.0 concepts in healthcare, construction, and manufacturing, as shown in Appendix 7, to ensure the model is practical and aligned with industry needs.
- Validation: Gathering feedback from experts, mainly professors, and Nokia personnel involved in 5G applications for industries, to ensure the model's feasibility and potential application.

Visualization Tool: The model was created using a tool called ICOGRAMS, which facilitated the creation of detailed and visually engaging representations of the proposed 5G-enabled university campus ecosystem.
4.2 5G University Impact Model

Inspired by the 5G University Test Network Finland, and the literature review, a 5G university impact model has been developed. This model illustrates a framework where universities, industry, and government collaborate to enhance the education experience and prepare students for the demands of the Fourth Industrial Revolution (4IR). Central to this model is 5G technology as the core driver of innovation and practical application across various educational domains.

Figure 22. 5G University impact model adapted from (Wessels and Van Wyk 2022).
The 5G University Impact Model comprises three key stages, each contributing to the overall transformation of the educational landscape:

1. **University Partnership (enabler):** Strategic alliances between universities, industry, and government drive the integration of 5G technology on campus. These partnerships facilitate the deployment of 5G infrastructure and collaborative research. The university becomes a hub for knowledge exchange and shared objectives.

   **Enhanced Education Experience (Driver):** 5G transforms education by enabling smart infrastructure. Improved teaching methods, innovative curriculum, and experiential learning opportunities enable students to connect theory with practice in a vibrant educational environment.

2. **Value Realization (Impact Perceived):** this stage reflects the tangible benefits of a 5G-enabled university campus. It produces highly skilled graduates who are prepared for the demands of the 4IR, contributing to a knowledge-based society. This stage emphasizes the broader economic and sustainable growth that results from a workforce equipped with advanced technological skills and innovative capabilities.
5 Conclusion and Discussion

This study set out with the main objective of determining how does 5G hyper-connected university campus enhances the education experience. The findings contribute significantly to the evolving topic of digital transformation in education, with a particular emphasis on the potential of 5G technology. The research identified several key benefits: enhanced learning environments, practical applications, and hands-on experience facilities, improved collaboration and innovation, overcoming traditional Wi-Fi limitations, fostering a prepared and skilled workforce, overall infrastructure improvement and student future preparedness for Industry 4.0.

Current efforts by telecom companies and operators such as Nokia, Verizon, and AT&T, alongside public investments in research projects like the 5G test network in Finland, demonstrate significant momentum in developing tangible 5G use cases with universities. However, the integration of high technology in universities remains quite slow. The challenge now lies in scaling these efforts to more university campuses to provide professors with advanced teaching resources, give students hands-on access to cutting-edge technology, and transform campus infrastructure. This requires addressing funding constraints, technical barriers, and increasing awareness and understanding of 5G technology among all university stakeholders.

5.1 Theoretical Impact

The development of the 5G Hyperconnected University Campus Conceptual Model and the accompanying 5G University Impact Model are significant contributions to the body of knowledge in this research area. These frameworks translate theoretical insights into practical applications, providing university administrators, educators, and students with a clear vision of the potential enabled by 5G technology.

The proposed conceptual model is grounded in the technological and industrial transformations currently unfolding in society, highlighting the demonstrated benefits of 5G
for I4.0. It posits that universities should provide a more hands-on learning experience that aligns with industry demands. Some universities have partially adopted this model in areas or study programs of particular interest. The initial validation from these partial implementations has confirmed numerous benefits in the teaching and learning experience, a sentiment underscored both through semi-structured interviews and visits to on-site university campuses in Finland.

The 5G University Impact Model theoretically illustrates the relevance of partnerships in contemporary society and the value realization of 5G deployment on university campuses. This model conceptualizes the university as a smart campus that supports hands-on learning, fosters innovation, and promotes the convergence of industry and academia. It proposes that skilled students equate to a prepared workforce and a knowledge society, leading to economic and sustainable growth.

However, for these two models to claim reproducibility and to be fully proven, further deployment, comprehensive integration across various university settings, and defined critical success factors are necessary. Continued research and application will be essential to thoroughly demonstrate the efficacy and impact of these two models.

5.2 Managerial Recommendations

For university administrators and policymakers, the study provides several actionable recommendations to facilitate the successful integration of 5G technology:

- **Define 5G Integration Roadmap based on university priorities:** Assess academic, administrative, and operational needs to identify 5G value areas. Align deployment with university goals for campus-wide integration.

- **Establish Collaborative Framework with Key Players:** Engage university leadership, telecom providers, and government bodies for tailored 5G initiatives aligned with local priorities. Foster ongoing dialogue, identify partnerships, and acquire resources for project support.
- **Forge Industry Partnerships for Campus Innovation**: establish strategic alliances with industry stakeholders to drive 5G innovation within the university ecosystem. Foster joint research projects and initiatives tailored to academic and industry needs.

- **Allocate Resources for Infrastructure and Pilot Projects**: Strategically invest in 5G infrastructure and prioritize pilot projects with clear objectives and scalability. Leverage the 5G Hyper-connected University Campus model for efficient resource allocation.

- **Develop Training and Awareness Campaigns**: Implement targeted programs to familiarize stakeholders with 5G technology and its applications across academia and operations.

- **Establish Governance and Stakeholder Engagement Structures**: Create robust governance mechanisms to facilitate transparent decision-making and stakeholder engagement throughout the deployment process.

- **Align with Sustainability Development Goals**: Integrate 5G deployment efforts with SDG to leverage smart solutions and align with the university's commitment to sustainability and social responsibility.

- **Engage Leading 5G Universities and Amplify Success Communication**: Collaborate with leading institutions for consultation and validation of benefits. Showcase project successes to boost momentum, university visibility, and enable potential additional funding for future initiatives.

While 5G technology holds significant promise for transforming the educational landscape, its successful integration requires addressing various challenges and developing a robust partnership ecosystem. By doing so, universities can create dynamic, innovative campuses that not only enhance educational outcomes but also contribute to broader societal and economic advancement.
6 Limitations and Future Research Directions.

This study on the 5G Hyper-Connected University Campus: Enhancing the Education Experience comes with its limitations. Firstly, the exploratory nature of this research and the limited existing literature on 5G integration in educational settings make it challenging to draw comparisons with traditional WiFi-enabled campuses. The interviews were confined to professors, students, and project managers in Finland, potentially resulting in a skewed perspective that does not fully represent broader, international viewpoints.

Additionally, the exclusion of top managers from the interview process may have limited insights into broader strategic and future planning aspects. The limited sample size of universities and students interviewed could further contribute to biased results. Furthermore, emerging technologies discussed, such as VR/AR, remote excavators, and Autonomous Mobile Robots are still in testing phases, hindering a comprehensive assessment of their real-world benefits.

There are ample avenues for future research to address these limitations. A critical area is the long-term effects of 5G integration on educational outcomes. Longitudinal studies tracking cohorts of students and faculty over several years could provide valuable insights into how sustained exposure to 5G-enabled technologies influences learning efficacy, engagement, and technological proficiency. Additionally, cross-disciplinary applications of 5G technology warrant thorough investigation. By exploring its use in fields beyond engineering and computer science, such as medicine, humanities, and social sciences, researchers can uncover novel ways in which 5G can enhance educational delivery and research capabilities across disciplines.

Another important area for future research is the scalability and replicability of successful 5G initiatives. Developing frameworks that facilitate the expansion of pilot projects to widespread adoption across multiple universities. This includes identifying best practices, potential challenges, and strategies for replication in diverse educational settings. Moreover, understanding the impact of 5G on pedagogical practices and instructional design is
essential. Furthermore, investigating the outcome of the 5G University campus impact model focused on the stage of value realization, including cost-benefit analyses, socio-economic barriers to adoption, and the potential for reducing educational inequalities, is necessary to fully grasp the transformative potential of 5G.

Finally, exploring effective collaboration models between universities, industry partners, and government entities, and understanding the perceptions and attitudes of students and faculty towards 5G technology will provide a comprehensive understanding of its impacts, guiding stakeholders in effectively harnessing its potential to transform the learning experience.
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Appendices

Appendix 1. Survey Request Email

Dear all,

I hope you are doing great!

I am writing to invite you to participate in a survey that is an essential part of my Master's thesis project. The survey aims to explore ways in which a 5G hyperconnected university campus can enhance the educational experience. Specifically, I am interested in analyzing the influence of three primary stakeholders:

1. Students
2. Professors and Administrative Staff
3. Campus infrastructure (smart building)

Your insights and creative thinking are incredibly valuable in shaping my research and contributing to a deeper understanding of this topic. Your participation not only enhances the quality of my thesis but also has the potential to pave the way for innovative initiatives and strategic partnerships in the field of education technology.

Please note the following information:
- Estimated Completion Time: 10-15 minutes
- Confidentiality: Your responses will be kept strictly confidential.
- Findings: Upon request, I will share the survey findings with you.

How to Participate: Please click on the following link to access the survey: https://forms.office.com/e/Zk8Xx9kK70?origin=lpLink

Please don't hesitate to contact me directly if you have any questions or if you would like to participate further in my research. Your willingness to contribute to academic research is highly valued, and I would like to express my sincere appreciation for your time and consideration.

Also, feel free to share the survey link with your networks. This will help us gather additional insights and make the study more compelling.

Thank you for your participation!

Br,
Lorena Gomez Gaviria
Master of Science in Technology
Global Management of Innovation and Technology Programme
Business Development Manager at Nokia
+358405840397

LUT University
Appendix 2. Survey Form

How does 5G hyper connected university campus enhance the education experience?

Ever wondered how the latest technology could transform the learning environment and experience on the university campus? I'm conducting a survey as part of my Master's thesis in Global Management of Innovation and Technology at LUT University. The aim is to delve into how the integration of 5G technology can enhance the education experience within a university campus, specifically focusing on key stakeholders: students, professors, administrative staff, and the infrastructure itself.

Please note the following practicalities:

1. The survey will take approximately 10-15 minutes to complete.
2. Alumni are kindly asked to base their responses on their experiences during their time at the university, while current students, professors, and administrative staff are invited to reflect on the current state.
3. To receive the survey results and contribute to the insights, please provide your email in the demographics section. Your participation is valued, and the findings will be shared with you.
4. For inquiries, insights, or collaboration opportunities, feel free to contact me via email at lorengomezovia@student.lut.fi. Your contributions and engagement are greatly appreciated.

About the Author
I'm Lorena Gomez, a strong believer in the transformative power of education for both personal growth and societal development. I have a high interest in international business and cooperation, partnership development, continuous learning, and exploring the world 🌍. Currently, I lead 5G business development at Nokia for the Nordics and Baltics while pursuing my Master's degree. My journey has taken me from South and North America, Europe, and Asia providing me with profound cross-cultural experiences. Through these experiences, I have come to deeply appreciate the global landscape of education and technology recognizing its pivotal role in navigating today's world challenges.

Demographics

1. Would you like to receive the survey results or be contacted to discuss the topic further and explore collaboration opportunities? If so, please provide your email address (optional)
   Enter your answer

2. Role: If you have already graduated from university, please select the role “Alumni” and share your experiences during your time at the university. Current students, professors, and administrative staff are invited to reflect on the current state of the university. *
   - Student
   - University professor
   - Administrative staff
   - University alumni
   - Other
3. Age *

- 18-24
- 25-34
- 35-44
- 45-54
- 55-64
- 65-70
- 70+

4. Country of origin *

Enter your answer

5. Completed or ongoing highest level of study *

- Bachelor or equivalent level
- Master or equivalent level
- PhD
- Other

6. Faculty or field of study *

- Faculty of Engineering
- Faculty of Information Technology
- Faculty of Business Administration
- Faculty of Health
- Faculty of Design
- Faculty of Law
- Faculty of Education
- Faculty of Arts
- Faculty of Economics
- Faculty of Humanities
- Faculty of Music
7. Name of the university you study, work or graduated *

Enter your answer

8. Country where the university is located *

Enter your answer

Section 2

Current connectivity and technology challenges

9. On a scale from poor to excellent, how would you rate the level of internet connectivity (Wi-Fi, network speed) on your university campus from your experience? *

<table>
<thead>
<tr>
<th>Poor</th>
<th>Fair</th>
<th>Average</th>
<th>Good</th>
<th>Excellent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tr>
</tbody>
</table>

10. Have you experienced any challenges with the internet connectivity on campus? *

- Yes
- No
- Not sure

11. If yes, please specify the challenges? *

Enter your answer

12. In your opinion, what are the areas where the university could improve in terms of technology adoption? You can select more than one *

- Faster connectivity
- Smart and virtual classrooms
- Emerging technologies like VR/AR
- Smart industry labs (smart factory, simulation hospital, smart construction field etc.)
- Research and innovation centers
- Cybersecurity measures
- Robotics
5G Awareness

13. On a scale from Nothing to Extensive, please rate your understanding of what 5G technology is? *

<table>
<thead>
<tr>
<th>Nothing</th>
<th>limited</th>
<th>Neutral</th>
<th>Good</th>
<th>Extensive</th>
</tr>
</thead>
<tbody>
<tr>
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</tbody>
</table>

Your understanding

14. What word or few words do you associate with 5G? *

Enter your answer

15. Pick the definitions of 5G that resonate most with your understanding of it? There are some incorrect definitions *

- [ ] Latest standard in mobile communication networks succeeding 4G LTE
- [ ] Faster speeds, lower latency (delay), more reliable connections, and greater capacity for wireless communication
- [ ] A type of satellite communication system
- [ ] Enables a wide range of new applications and services such as AR, VR and the IoT
- [ ] Customizable network Slices
- [ ] 5 gigabytes and is a new storage technology for smartphones
- [ ] All of the Above
- [ ] Not sure
- [ ] Other

16. Imagine you’ve received a generous donation of 1 Million Euros to invest in your university’s future. If you have the freedom to choose, which three options would you prioritize for investment? Feel free to propose your own innovative investment idea *

Please select 3 options.

- [ ] Increasing staff salaries and hiring new professors
- [ ] Investing in campus expansion and modernisation, or constructing new buildings
- [ ] Acquiring emerging and advanced technology devices.
- [ ] Upgrading the network infrastructure to 5G wireless technology
- [ ] Establishing a 5G research center to drive innovation and collaboration with industry partners.
- [ ] Creating a scholarship program to support students pursuing studies in emerging technologies
17. On a scale from very low (indicating minimal belief) to very high (indicating strong belief) to what extent do you believe the adoption of 5G can help universities achieve the following objectives? *

<table>
<thead>
<tr>
<th>Enhanced Connectivity: seamless communication and collaboration among students, faculty, and staff across campus</th>
<th>Very low</th>
<th>Low</th>
<th>Neutral</th>
<th>High</th>
<th>Very high</th>
</tr>
</thead>
<tbody>
<tr>
<td>Improved Learning Experience: Immersive and interactive learning experiences</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Innovative Research: advanced research initiatives by access to massive amounts of data, real-time analysis, advanced equipment and remote collaboration</td>
<td></td>
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<tr>
<td>Sustainable Campus Initiatives: Implement sustainability initiatives for energy, air monitoring, waste and water management</td>
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</tr>
<tr>
<td>Efficient Operations: deployment of smart solutions, such as intelligent transportation, AGVs, automated facilities, cameras, etc.</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Innovation and Entrepreneurship: support innovation hubs, incubators, making spaces on campus more practical with advanced and emerging technology</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Develop better industry partnerships to a more innovative and industry-aligned educational experience</td>
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</tr>
<tr>
<td>Data-Driven decision making: gather and analyze vast amounts of data on student behavior, campus usage patterns, and academic performance to improve campus management strategies</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

18. In which departments or areas do you think these initiatives can benefit the most? *

- [ ] Research, development and innovation
- [ ] Engineering
- [ ] Computer Science/Information Technology
19. What could be the possible challenges or concerns associated with the implementation of a Smart University Campus using 5G technology? *

Enter your answer

20. Are you aware of any company developing and deploying 5G technology in universities? *

- Yes
- No
- Not sure

21. If yes, please specify the company or companies you are aware of:

Enter your answer

**Industry Partnerships and Innovation**

22. In your opinion, what are the **benefits of collaborating** with companies or government institutions to further develop and adopt 5G technology for education? *

Please select 3 options.

- Development of new curriculums and degrees
- Opportunities for student internships and experiential learning
- Access to industry expertise and resources
☐ Enhanced student learning and career opportunities

☐ Bridge the gap between academia and workplace needs for industry 4.0

☐ Establish industry partnership ecosystems within university settings

☐ Expanding students’ exposure to industry events, projects, seminars, and technology collaborations across diverse degree programs.

☐ Other

23. Success Stories and Best Practices: Can you share any success stories or best practices from your university or other higher education institutions regarding partnerships and innovation in the context of advanced technology adoption, including 5G? If you do not know any please add N/A.

Enter your answer

24. Imagine you are the Director of a forward-thinking university, and you are meeting with high-level representatives from government, industry, and academia. What types of partnerships would you propose for your university to enhance the university experience?

Enter your answer

Section 5

Gratitude and follow-up.

Thank you for taking the time to complete this survey. Your insights are invaluable and will greatly contribute to my thesis project. Please provide your contact information below if you have any further comments or are interested in a follow-up interview.

Contact Information (Optional):
Appendix 3. Online Interview Gratitude and Summary Email

Dear Professors,

I wanted to thank you for the time spent discussing my thesis topic related to the enablement of 5G technology in universities and its benefits to enhance the overall education experience, all your insights were well captured and very appreciated, I’m very impressed by all the projects Savonia University is working on and would be great to schedule a visit to your university to see them closely!

In case you have more information related to projects, initiatives, use cases, or collaborations, please share them with me (maybe publications, press releases, videos, links etc.), it would be great to capture them in my thesis, also they will help as a benchmark for other universities that would like to endeavor in the 5G journey.

Please find below the summary of the questions we had during our meeting, feel free to add more information where you find relevant:

Questions
- Can you provide an overview of how Nokia's 5G technology has been deployed on our university campus?
- What specific features or capabilities does the 5G infrastructure offer in enhancing connectivity and communication within the campus?

User Experience and Impact:
- How have students and faculty members responded to the implementation of 5G technology on campus?
- Have there been any noticeable improvements in terms of internet speed, reliability, or access to educational resources since the deployment of 5G?

Use Cases and Applications:
- Can you share any notable use cases or applications enabled by 5G technology in your campus?
- How are educators leveraging 5G connectivity to enhance teaching methods and deliver content to students?

Collaboration and Innovation Opportunities:
- In what ways has 5G connectivity facilitated collaboration between academia, industry partners, and government entities?
- Are there any initiatives or projects on campus that showcase the collaborative potential of a hyper-connected environment enabled by 5G?

Challenges and Considerations:
Have there been any challenges or obstacles encountered during the implementation of 5G technology on our campus?

Future Directions and Opportunities:
- What are the potential future directions for leveraging 5G technology to further enhance the education experience in your campus?
• Are there any emerging trends or innovations in 5G-enabled education that your university should consider exploring?

Involvement and Feedback:
• How are students being actively involved in shaping and contributing to the utilization of 5G technology on campus?
• Do the professors, administrative and management of the universities know about the potential of 5G and they get involved in some projects?

Thanks, and looking forward to continuing our discussion and cooperating for 5G related projects in universities
Br

Lorena Gomez Gaviria
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CNS ECE Europe
Contact number: +358405840397

At Nokia, we create technology that helps the world act together.
Appendix 4. 5G University Test Bed F2F invitation and agenda

Dear Rajeev and Aki,

First, I’d like to thank you once again for hosting me and sharing the great 5G initiatives happening at your university. To make the most of our time together, I have prepared an agenda that we can adjust as needed.

Also, I would need your permission to record certain areas of the university where 5G is being applied. I will use this footage to create a video at the end of my thesis showcasing all the universities in Finland that are conducting 5G R&D. The goal is to make this video a global reference for 5G-hyperconnected university campuses.

Agenda:

Exploring University 4.0 and 5G Testbed Deployment- Savonia Applied Science University

- Duration: 2 hours

**Introduction (15 minutes)**
- Welcome and Introduction to the University
- Brief Overview of University 4.0 Concept and 5G Testbed Deployment

**Campus tour (45min)**
- Visit key locations where 5G infrastructure is deployed
- Deep Dive into 5G Testbed Deployment- technical aspects
- Introduction to different technologies incorporated into the campus infrastructure
- Deep dive into 5G-enabled use cases
- Quick overview of ongoing projects/initiatives related to 5G technology

**Knowledge sharing session: (30min)**
- What are the benefits of 5G Technology for University Campus
  - Increased Connectivity and Bandwidth
  - Support for Innovative Research and Development
  - Enhanced Learning Opportunities
  - Improved Campus Safety and Security
  - Bridge gap between academia and real job demands

**Partnerships and Corporate collaborations**
- Companies involved and type of projects
- Type of partnership
- Partnership relationship management
- Discussion on potential collaborations and future engagements

**Interactive Session and Interviews (30 minutes)**
- Showcase of ongoing initiatives and projects leveraging 5G technology
• Opportunity to conduct short interviews with key personnel (faculty, researchers, students) involved in 5G projects
• Conclusion and closing

Please feel free to invite anyone from the university whom you consider relevant to discuss the agenda items shared.

Thank you, and I am eagerly looking forward to our meeting on Tuesday, the 16th at 10 am.

Best regards.

**Lorena Gomez Gaviria**
Enterprise PWLs Campus Sales Manager - Nordics
CNS ECE Europe
Contact number: +358405840397

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At Nokia, we create technology that helps the world act together.
Appendix 5. University Campus 5G use cases and projects

Figure 23. University of Oulu 5G Network Infrastructure (University of Oulu 2024).

Figure 24. Energy- and cost-efficient production of solar energy under arctic environmental conditions (University of Oulu 2024).
Figure 25. Tampere University 5G Infrastructure (Tampere University 2024).

Figure 26. Tampere University 5G Research Laboratory (Tampere University 2024).
Figure 27. Smart Factory Simulation (Savonia University 2024).

Figure 28. Remote Control Excavation Lab (Savonia University 2024).
Figure 29 Autonomous Robotics Lab (Savonia University 2024).

Figure 30. 5G Smart Water Lab (Savonia University 2024)
Figure 31. Autonomous Remote control over 5G (LAMK 2024).

Figure 32. Research Campus ARENA 2036 (Nokia 2019)

Appendix 6. 5G Test Network Finland Ecosystem

Figure 33. 5GTNF ecosystem partners
Appendix 7. 5G Industry 4.0 Models

**Healthcare use cases in smart hospitals**
Enhanced patient care, digitalized health operations and integrated building automation

**Key technology requirements...**
- High performance (HD images/videos)
- Data security (EHR, health data)
- Low latency (real-time, "no delay")
- On-site computing (edge data processing)

Figure 34. 5G Smart Hospital (Nokia 2022)

**Construction use cases demonstrated in the smart site**

Figure 35. 5G Smart Construction Site (Nokia 2022)
Figure 36. 5G Smart Manufacturing (Nokia 2021)