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What Not to Do: VR Implementation Teams and the Barriers That Inhibit Them

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Abstract. Implementation of VR into NPD processes requires a coordinated effort from within the manufacturing organization. However, the knowledge to carry this out successfully is still quite limited within research as well as within manufacturing organizations, leading to failed pilot projects and a waste of resources. Therefore, the purpose of this paper is to identify barriers that inhibit VR implementation. A multiple case study has been carried out focusing on two VR implementation attempts within a single manufacturing site. The results identify four specific roles and their responsibilities within the VR implementation teams: Key driver, gatekeeper, key user, and general user. The results further identify the barriers experienced within the VR implementation attempts.

Keywords. Smart production, digitalization, manufacturing, Industry 4.0, NPD

1. Introduction

By using Virtual Reality (VR) during New Product Development (NPD) processes, manufacturing organizations can reduce time-to-market (TTM)[1], [2]. Research and applications relating to VR have steadily increased across industries such as in automotive and heavy machinery industries due in large part to these promises [3], [4], [5]. VR is a technology that allows users to experience a 3D prototype of a large, complex product in a virtual world in early design phases during New Product Development (NPD) processes. Previous research has explored VR usage and application areas within the NPD process and has been proven to be pivotal when viewing and interacting with virtual, life-sized objects for testing ergonomics and manufacturing processes [6]. VR demonstrates potential to enable shorter TTM in NPD projects, however the recipe to achieve this is still a question [7]. Manufacturing organizations are now challenged with transitioning their sporadic usage of VR towards planned and consistent utilization of the technology, or in other words, implementation.

General studies of technology implementation today argue that it is the human aspect that is the key element that organizations should manage to successfully transition towards and implement new technology [8]. A successful implementation of a new technology, such as VR into the NPD process, must be a coordinated effort between several levels of workforce roles, ranging from upper management down to the general

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user of the technology itself [9]. Butt (2020) further describes that a team is necessary to carry out a full-scale implementation. Unfortunately, knowledge and literature on implementation of VR technology into NPD processes is very limited [4], [7], [11], especially concerning the level of full-scale implementation needed for an organization to attain shorter TTM through VR usage. Organizations are also experiencing many difficulties when implementing VR into NPD processes, especially from organizational and process dimensions [12], as in how implementation is managed and how ways-of-working are carried out. Therefore, due to the gaps in literature and the difficulties experienced in industry, a way forward can be to explore some less than successful VR implementation attempts, or those attempts which have not fully succeeded after their initial startups.

Thus, the purpose of this paper is to explore teams implementing VR within the NPD process and to identify the barriers influencing them.

2. Theoretical background

2.1. Usage of Virtual Reality (VR) in the NPD process

The manufacturing industry is increasingly utilizing VR technology within their development processes, including both product development and production development processes [5], [13]. Berg & Vance (2017) describe in their literature review that VR is used within various phases of the product development process, including the design phase such as testing driver visibility, testing ergonomics and reachability, and evaluating aesthetic qualities such as lighting. The authors further describe that VR is used within planning the organization of large spaces, such as production layouts, where controls and tools can be placed to support decisions in the layout. VR is further used in production development specifically for analyzing the usability of sections in a factory, including assembly, ergonomics, layouts, maintenance, and training [5].

2.2. Technology Implementation Teams

The subject of technology implementation teams is described in several ways in literature, including making sense of what implementation teams are altogether, the overall impact of implementation teams, and what roles are included within such a team (Ref).

From the innovation perspective, Johnsson (2017) defines an innovation team as a cross-functional team within an organization with the purpose of conducting innovation work. The author further states that there are three types of considerations relevant to these types of teams: the organizational context, management of the team itself, and the individuals within the team. Innovation is said to be something that is developed, such as product or process, and ultimately creates added value. Thus, the innovation team is tasked with carrying out this innovation. From an industry 4.0 technology implementation standpoint, Butt (2020) describes that teams are created and are vital to ensure one overall vision for an implementation. Furthermore, the team helps to identify functional needs and priorities, and identifies the needed changes from inter- and intra-organizational perspectives. Butt (2020) further describes the importance of teams for the implementation of new technologies, and how the implementation process should be described into a detailed plan and describe the characteristics of work in each implementation phase.

Implementation teams are noted to have a variety of roles within them. Csiki et al. (2023) conducted a literature review and classifies three main employee groups according to three technology implementation phases. The main employee groups include managers, development experts, and employees. The author further describes each roles' different skills required from the different roles in order to achieve successful implementation. Butt (2020) describes that the implementation team should comprise practitioners, and not just those in senior management, but experienced personnel as well. The author further describes that experienced personnel should be trained to become 'digital key users' who can help drive the initiative to implement and create a sense of ownership among the workforce [16]. Butt (2020) also describes that a 'steering board for digital implementation' should be established, which should involve senior management which allows to contribute their experience.

2.3. Technology Integration Barriers

Barriers to technology integration, and thus the teams carrying it out, are described from different viewpoints. Butt (2020) describes the barriers faced by an organization's workforce as a whole, such that barriers to technology implementation are largely due to resistance to change, and therefore it is crucial to manage and support the workforce towards the transition. The management and support of new technology will influence the overall acceptance of technology and thereby acceptance of change. Technology acceptance is largely defined as how individuals' perceptions affect their intentions to use technology as well as its actual usage. Management and support for fostering technology acceptance includes variables such as promoting collective awareness and involvement, improving workers' knowledge through both technical and soft skills, and developing effective users of the new tools with specific training courses to teach how to use the technology [17]. Therefore, failure to manage and support these variables would lead to a resistance to change and technology acceptance.

Other literature describes barriers at different organization levels, such as managers or employees specifically [15]. Schneider (2018) clusters managerial challenges into strategy and analysis, planning and implementation, cooperation and networks, business models, human resources, and change and leadership. Underneath change and leadership specifically, challenges arise from bottom-up implementation projects, stemming from acceptance problems and resistance to necessary changes by both managers and users. One of the main challenges experienced by employees is an increase in job complexity [19], [20] This can further lead to work over-load and stress [21].

3. Methodology and Case Description

The purpose of this paper is to explore teams implementing VR within the NPD process and to identify the barriers influencing them, hence a multiple case study has been conducted. The case study allows deeper understanding of the nature and complexity of a complete phenomenon and the multiple case study design enables the comparison between cases as well as the possibility to generalize findings [22].

The research is conducted at a production site in Sweden, carrying out both product development for an entire product platform as well as production of these products. The site is a part of a larger global manufacturing organization within the heavy vehicle industry. VR implementation was first initiated at the site in 2019 with a company standardized VR software and its usage continues today. Implementations have been carried out during early development phases of two NPD projects. Case A follows a VR implementation process from the technology's first introduction in 2019 until early 2021. The technology was used primarily for ergonomics testing within a sub-assembly of a larger product. Case B follows a second VR implementation process starting in 2022, which continues today. The technology is used primarily towards design for service and assembly sequences within a full product. The study examines the two cases from the perspective of the core team members who took part in the implementation of the VR technology within the NPD project. Both cases utilized VR for virtual prototyping in early design stages as well as physical prototypes.

Data has been collected through interviews during 2023. Interviews were semi-structured and covered subjects relating to the interviewees' role in the organization, their role in the VR implementation process, their overall experience within the process such as barriers, and their thoughts on possible mitigations. Interviews spanned approximately 1 hour. Three managers were interviewed at the site. One oversees the development of a particular product platform, and two are project leaders for specific NPD projects within the product platform. Four engineers were interviewed at the site, two from each of the NPD projects.

Additional data has also been collected through presentations and internal documents. The author of this paper has been present on the site for the duration of the study, on average one day per week, granting further access to observations and input into ongoing VR implementation phenomena.

Implementation roles have been analyzed and assigned to Management and Users based on roles suggested by literature [15], and then further developed through a data driven process. Data analysis has been conducted through the thematic analysis method [23] to identify reoccurring barriers in the data. Barriers were then assigned to people, technology, and process dimensions [24]. The identified barriers and roles were then described in terms of how they relate to each other according to what was said in interviews.

4. Findings

The following describes the results from the study. (1) the roles within the VR implementation team, (2) the barriers that the individual roles faced during the implementation, (3) the team roles and barriers mapped according to how they interface with one another.

4.1. VR Implementation Team Roles

In both case A and B, implementation teams were created, and two main roles were identified when implementing VR at the production site, Managers and Users. The identified roles were further divided into four specific roles: (1) Top-driver, (2) Gatekeeper, (3) Key user, and (4) General user. The top-driver was responsible for getting initial funding for the VR equipment, developing a vision for the usage of the technology, and supporting VR implementation through weekly meetings with gatekeepers, key users, users, and other product stakeholders (pre-pandemic). The Top-driver also supported VR key users with contacts to other production sites that worked with VR. Furthermore, the top-driver arranged a kick-off day at the beginning of the implementation in order to present the vision of the VR's, reasonings why VR was to be used, and ways-of-working recommendations such as having weekly meets.

The gatekeepers are the project leaders responsible for NPD projects and keep them on schedule according to a specific timeline. In NPD projects gatekeepers are responsible for communicating needs between stakeholders in different departments, such as R&D, production, purchasing, and aftermarket. All stakeholders have accepted the usage of VR as they see it as a tool that would add value such as in prototyping and in communicating early designs to other stakeholders. The gatekeepers depend on key users to create all VR work for communications purposes.

The key users have expert VR knowledge. Their main role during the VR implementation included being responsible for the VR lab, attending bi-weekly online support meets for VR, and facilitating others to use VR. These key users naturally became VR experts because they had some previous experience and a natural curiosity for it. Key users found VR technology to be a good fit and tool for their daily work and saw great value in using it. In Case A, the key user left the project to take on another role in the organization. The general user role is a VR user who uses VR in their general work, but to a much less extent than the key users. In Case A, these general users attempted to learn and use the software, however they ended up stopping to use it altogether. Case B general users use VR sparingly and depend on the key user to create VR environments to validate designs.

The following table describes the responsibilities of the individual roles.

Table 1. Implementation team roles and responsibilities

Main roles	Role	Responsibilities
Managers	Top driver	• Implementing VR at site • Getting initial funding for equipment • Kicking off project with pilot team and vision • Continuous improvement meetings (before pandemic) • Gives support to those interested in VR, especially VR key users
	Gatekeeper	• Plan and carry out activities within the NPD process • Communicate NPD updates to other stakeholders with VR support
Users	Key user	• Responsible for VR lab and keeping software updated • Facilitating others to work with VR • Incorporate VR usage into their own work for validation needs • Create VR environments for the managers
	General user	• Use VR in their general work

4.2. Barriers

The barriers that the individual roles faced during the implementation process can be seen in the table below. The barriers are categorized among three dimensions, People, Technology, and Process. It is further visualized which role encountered the barrier.

Table 2. Categorized barriers and the role which was influenced. (Indirect experiences are barriers to a specific role that have been suggested by another role during interviews)

Dimension	Barriers		Influenced role
People	Loss of key user		■
	Lack of critical mass		■ ♥
	Lack of perceived value		△
	Skills development issues		△
Technology	Set-up preparation difficulties		△
	Distrust in technology		△
Process	Lack of standardized way-of-working		▼ ■ ♥
	Unforeseen events		▼ ■ ♥
Key: Roles	**Managers**	**Users**	
	▼ Top driver	♥ Key user	Filled (▲) = Direct experience
	■ Gatekeeper	▲ General user	Outline (△) = Indirect experience

<u>People:</u> The barriers found in this dimension are all closely tied together. The key resource in sustaining VR usage at a site is typically the key user, so therefore when there is a *Loss of key user,* for example of by leaving the company or changing role, a competence void is left. The key user is typically the one who is a cheerleader to others, or a 'driving star', who other VR users can come to for in-person support, the one who is mainly responsible for readying different virtual environments for teams, and keeps software and hardware updated within the VR room itself. If the key user leaves, this can easily spell the end of the usage of VR within the department. This is especially the case when combined with the *Lack of critical mass* barrier, which can entail that there is no other person ready to take up the task, either due to their own *Lack in perceived value* of the technology, or their low level of VR skills development. This barrier affects the gatekeepers, or those who make use of VR to communicate with other stakeholders. The gatekeepers largely depend on their key users to make ready the VR environments and leading VR validations and visualization walk-throughs. Once they lose the VR key user from their department, the department can lose all knowledge about the VR technology in general. As one gatekeeper noted after losing the VR key user, "We are lacking a guiding star to support and help. Who is taking care of that [VR] room?"

VR implementation requires a range of different stakeholders as well as a certain 'mass' to be sustained within a site. This includes managers at different levels within the site, supporting roles such as VR key users, as well as the general users. Managers, such as the top-drivers and gatekeepers, are needed to transform project processes to include and call for virtual prototype validations. If the managers do not push for this, then the virtual prototype will be deprioritized by the engineers (users). More supporting roles, such as key users, are needed in case one key user changes roles. A singular key user also experiences being the bottleneck in VR processes. They find they don't have the time to give full support to multiple virtual prototypes at once, as they themselves are busy with their own projects. This eventually stunts the growth and perceived value of the VR within the site and can lead to a continued decrease in usage. Furthermore, a lack in VR key users means that the VR will not diffuse to other projects within the same site, as the VR tends to be owned and grow within the same department as the VR key user.

A similar explanation can be given to the low amount of general VR users, which also blocks the growth of the technology within a site. According to the VR key users, general VR users are difficult to onboard using VR, due to both lack of perceived value and *Skills development issues*. According to the key users who try to onboard users, they don't find VR to be of any value as their current software already does the job that they need to fulfill, and therefore they don't see a point in overcoming the learning curve for a new software. General issues include not receiving proper training in VR functionality which corresponds to the individual engineer's work, and insufficient usage of the software, leading to the user forgetting how to use it altogether. In the cases studied here, users stopped using the software altogether, instead relying on the VR key user to create all of the VR scenarios for the team instead. The lack of critical mass, lack of perceived value, and skills development issues have affected the gatekeepers and key users.

Technology: The VR technology itself continues to have issues which act as barriers to the sustained usage of VR at the site. According to VR key users, these barriers affect the general users the most. Barriers include difficult data streams of CAD files into the VR software, as CAD files can become corrupted during transfer. Simply getting the software and hardware up and running is also a barrier to the general user, as well as spending the necessary time to design the VR environment from the CAD data. These cause just enough annoyance to a general user to become a full-stop barrier to them. As mentioned above, this will negatively influence onboarding more users, not allowing a critical mass of users to be reached.

Decreasing physical prototypes and increasing virtual prototypes through the use of VR is the goal with its implementation, however a large number of stakeholders still ultimately prefer the physical over the virtual when conducting certain tests, even if a virtual prototype has been planned for. According to one Gatekeeper, "The plan was definitely to just do it in VR, but the hesitation of not having the safety of the physical build [led us to skip the VR and go straight to a physical prototype]". This *Distrust in technology* can stem from the knowledge that some components are necessary to test through physical contact, such as a foot on a gas lever, or the position of a driver in a chair. As one VR key user described, "…even if people were sitting in the VR experiencing the operator environment, we had to also understand that they may be sitting in the wrong position [due to a difference in the virtual and physical position of a chair]." Further distrust emerges in phases when the VR environment is being set up. Countless hours can be spent preparing an environment. However, the software itself has a rather annoying attribute which occurs when updated software versions are rolled out, which can be often at times. During an update, the VR scene, and all the hours spent, are simply erased, and must be redone. One VR key user commented that this is a huge barrier to the general user, ""…[the version handling] was questioned by the engineers… if we need to do this from scratch again, then what's the use?" These technology barriers have tended to obstruct the general users from attempting to continue with the technology, according to the VR key users. The VR key users have already overcome the hurdles associated with setup difficulties and they also have the knowledge to understand what should indeed be trusted in the VR environment, therefore they have not been affected by these barriers. The Gatekeeper has the most control over whether a large virtual validation session will be conducted, and if they don't have full trust in the virtual, they will still prefer a physical prototype to be built. The virtual would have allowed for more iterations, but if time is very constrained, then the time for concept validations is over, the project will move on, prioritizing a full physical build for the next development phase.

Process: *Lack of standardized way-of-working* can be considered the foundation (or lack thereof) which the VR implementation needs to be able to survive. Without a clear vision, VR activities to be carried out, processes to carry out activities, and delegated roles, the chance of incorporating VR into the NPD process, and thus engineers' workflows, becomes quite difficult. As one VR key user described, "I don't know if it was exactly clear, the vision that if it was communicated in a way so that we all knew what was expected or the end result of this, it was more like now we're going to learn this tool, we will have the VR labs and let's start use it." Furthermore, with a lack in standardized processes, the different cases carried out VR activities in a range of different ways, from ad-hoc mini visualizations, to small weekly validations, to twice per year full validations with up to 20 stakeholders. This range in activities led to extra work and confusion for the VR key users and general users, as they didn't always know what to expect or know what to adjust their existing work processes for. This lack in standardized process extended to the master NPD schedule as well. Gatekeepers either planned for a large VR validation event in the master NPD and then skipped it (Case B), or Gatekeepers forewent including the event altogether (Case A). These scenarios further led to confusion and deprioritizing the VR technology.

Lack of standardized way-of-working is further magnified by any *Unforeseen events,* as the processes are not robust enough to sustain momentum on their own. In one Case A failed around the time of the pandemic, and all stakeholders described that the pandemic was a major disruption to the lightly rooted processes. As the main driver mentioned, "I stopped all these meetings due to the pandemic and then no one gathered the people that were working [with VR]. I didn't start up the VR network again due to the pandemic, as I had too much else going on that I needed to prioritize."

5. Discussion

The purpose of this paper is to explore teams implementing VR within the NPD process and to identify the barriers influencing them. This research uncovers two role groups; (1) managers and (2) users, and four sub-roles; (1) Top-driver, (2) gatekeeper, (3) key user, and (4) general user. The barriers experienced by different roles are also identified and are categorized in the dimensions people, technology, and process.

The successful implementation of a new technology such as VR is highly dependent on the team of people carrying out the implementation. Within the two cases, the implementation teams proved to be comprised of two main role groups, managers and users. At first, these identified main role groups seem to fulfill the prime roles necessary for a successful implementation [15]. However, as the implementations can be described as less-than-successful within the cases, it begs the question of what is lacking within the teams. Expanding upon these main roles alludes to the fact that some sub-roles may be lacking. For instance, within management, the absence of a steering committee and senior management within VR implementation seems to have negatively affected the success of the implementation teams [10]. Furthermore, a lack of enough of personnel fulfilling certain roles also negatively affects the implementation team, such as key users [10]. The different roles in the team naturally performed different responsibilities during the implementation, and therefore a lack in certain roles would have hindered the implementation.

The four sub-roles performed various responsibilities. Within the existing teams, the top-driver acquired the funding for the technology, created a vision for the use of the technology, and led the team through the vision of the implementation. Their project role was to plan and carry out activities to bring the development of the product further within the scheduled process. However, it was expressed by all other sub-roles in the implementation team that the vision was unclear and confusing, especially in terms of how to make changes and restructure the work to include the new VR technology. Furthermore, VR implementation activities were not as strongly planned for (Case A) nor prioritized for (Case B) within the NPD process. The lack of clear vision and detailed plan showcases that a lack in experienced VR implementation personnel was a large factor in the resulting failed implementation. This lacking role led to a lack in knowledge surrounding of how a detailed plan and characteristics should have been adopted in the first place [10]. This also showcases that the lack in a specific role led to lack in sufficient knowledge to manage and support not just the technical skills, but also the soft skills such as ways-of-working. Due to this lack in support, the teams ultimately resisted the change and failed to accept the technology [17].

The existing implementation teams also incorporated some key users, one key user in each case. However, these key users experienced bottleneck scenarios, as the majority of the VR work ultimately became their responsibility, such as creating the VR experiences. The findings show that the key users were not able to carry the workload within their current role descriptions. This led to work over-load and even additional stress [21]. Furthermore, with a lack of standardized way-of-working, the users experienced a much higher degree of job complexity [19], [20]. This may have been the result of either the lack of enough key users, as this would inhibit the lack of drive and sense of ownership [10] or the lack in sufficient planning from other roles. Ultimately, the lack of different roles or enough of personnel within a role seems to lead to unsustainable workloads for the existing people within the team.

The formation of the implementation team has a large effect on the success of new technology implementation, as showcased by the two cases. Failure to form a team with key roles, such as within management, or enough people, such as within users, greatly affects the outcome of the implementation attempt due to the different responsibilities carried out by the roles. The different roles within the team depend on each other, management on the users, and users on management. Management provides guidance and support to the users, and users provide value to the managers from using the technology. Due to this dependence, the lack of roles and the resulting barriers lead to resistance to change and the technology not being accepted. Ultimately the team becomes too weak to support itself anymore and the technology is either discarded or used sparingly. Overall, this shows the importance of developing a team with all necessary sub-roles to achieve a successful technology implementation. This begs the question of how many more roles are indeed necessary to tip the scales towards success.

6. Conclusions

The presented research uncovers the existence of different roles present in current VR implementation teams and the responsibilities carried out by different roles. Some sub-roles may have been lacking [10], which may have contributed to the resulting less-than-successful implementation attempts. The research also identifies barriers which have affected teams during VR implementation attempts through people, technology, and process dimensions. It can be concluded that roles are heavily dependent on one another, and therefore the barriers experienced between the separate roles magnify each other.

To mitigate the barriers experienced in the showcased cases, certain roles in management should be present, such as experienced VR implementation personnel. From the beginning and throughout the implementation, personnel with expert implementation experience should be present and provide feedback during the planning and carrying out of an implementation roadmap. More planning and commitment is also needed from management for VR activities within the master NPD schedule. Lastly, management should focus energy on increasing the amount of key users, even forming an expert group within a given site, and decrease energy on onboarding general users.

This study contributes to literature by uncovering more specifics on the phenomena of VR implementation into NPD processes, as well as roles or lack thereof in implementation teams. Practitioners can use this work to increase the likelihood of a successful VR implementation by having awareness of potential barriers and by making informed initial decisions during the design of an implementation. Managers may consider hiring more engineers for the sole purpose of creating VR at a site, as well as to schedule specific activities within the master schedule for VR validation sessions.

Future recommended studies include incorporating more case studies, especially from sites that have experienced successful VR implementations to validate and expand upon the team roles. It is also recommended to identify the activities necessary to be planned for and carried out during the implementation.

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References

[1] L. Fernando de Souza Cardoso, F. C. M. Q. Mariano, and E. R. Zorzal, "A survey of industrial augmented reality," *Comput Ind Eng*, vol. 139, Jan. 2020.

[2] S. C. Sekaran, H. J. Yap, S. N. Musa, K. E. Liew, C. H. Tan, and A. Aman, "The implementation of virtual reality in digital factory-a comprehensive review," *The International Journal of Advanced Manufacturing Technology*, vol. 115, pp. 1349–1366, 2021.

[3] H. Jalo, H. Pirkkalainen, · Osku Torro, E. Pessot, A. Zangiacomi, and · Aleksei Tepljakov, "Extended reality technologies in small and medium-sized European industrial companies: level of awareness, diffusion and enablers of adoption," *Virtual Real*, 2022.

[4] M. Saghafian, K. Laumann, and M. R. Skogstad, "Organizational Challenges of Development and Implementation of Virtual Reality Solution for Industrial Operation," *Front Psychol*, 2021.

[5] S. M. Ventura, R. Fellow, F. Castronovo, and A. L. C. Ciribini, "A design review session protocol for the implementation of immersive virtual reality in usability-focused analysis," *Journal of Information Technology in Construction (ITcon)*, vol. 25, pp. 233–253, 2020.

[6] G. G. Wang, "Definition and review of virtual prototyping," *J Comput Inf Sci Eng*, vol. 2, no. 3, pp. 232–236, Sep. 2002.

[7] J. Wolfartsberger, "Analyzing the potential of Virtual Reality for engineering design review," *Autom Constr*, vol. 104, pp. 27–37, Aug. 2019.

[8] E. Kaasinen *et al.*, "Empowering and engaging industrial workers with Operator 4.0 solutions," *Comput Ind Eng*, vol. 139, Jan. 2020.

[9] L. Sz and K. Demeter, "Industry 4.0: a review and analysis of contingency and performance effects".

[10] J. Butt, "A strategic roadmap for the manufacturing industry to implement industry 4.0," *Designs*, vol. 4, no. 2. MDPI AG, pp. 1–31, Jun. 01, 2020.

[11] J. M. Davila Delgado, L. Oyedele, P. Demian, and T. Beach, "A research agenda for augmented and virtual reality in architecture, engineering and construction," *Advanced Engineering Informatics*, vol. 45, Aug. 2020.

[12] B. Sauter, A. Granlund, M. Ahlskog, J. Bruch, and V. Badasjane, "Integrating XR technologies in the product realization process: Current approaches and challenges," in *European Operations Management Association*, Leuven, 2023.

[13] L. P. Berg and J. M. Vance, "Industry use of virtual reality in product design and manufacturing: a survey," *Virtual Real*, vol. 21, pp. 1–17, 2017.

[14] M. Johnsson, "Innovation Enablers for Innovation Teams-A Review," *Journal of Innovation Management Johnsson JIM*, vol. 5, pp. 75–121, 2017.

[15] O. Csíki, L. Szász, K. Demeter, D. Losonci, and B.-G. Rácz, "What is the role of human resources in the adoption of digital manufacturing technologies?," in *European Operations Management Association*, Leuven, 2023.

[16] G. May and B. Stahl, "The significance of organizational change management for sustainable competitiveness in manufacturing: Exploring the firm archetypes," *Int. J. Prod. Res.*, vol. 55, pp. 4450–4465, 2017.

[17] M. Molino, C. G. Cortese, and C. Ghislieri, "The Promotion of Technology Acceptance and Work Engagement in Industry 4.0: From Personal Resources to Information and Training".

[18] P. Schneider, "Managerial challenges of Industry 4.0: an empirically backed research agenda for a nascent field," *Review of Managerial Science*, vol. 12, no. 3. Springer Verlag, pp. 803–848, Jul. 01, 2018.

[19] Y. Vereycken, M. Ramioul, S. Desiere, and M. Bal, "Human resource practices accompanying industry 4.0 in European manufacturing industry," *J. of Manufacturing Technology Management*, vol. 32, no. 5, pp. 1016–1036, 2021.

[20] Y. D. Ozkan-Ozen and Y. Kazancoglu, "Analysing workforce development challenges in the Industry 4.0," *Int. J. of Manpower*, vol. 43, no. 2, pp. 310–333, 2022.

[21] N. Malik, S. N. Tripathi, A. K. Kar, and S. Gupta, "Impact of artificial intelligence on employees working in industry 4.0 led organizations," *Int. J. of Manpower*, pp. 334–354, 2022.

[22] R. Yin, *Case Study Research and Applications: Design and Methods*, 6th edition. London: Sage, 2018.

[23] V. Braun and V. Clarke, "Using thematic analysis in psychology," *Qual Res Psychol*, vol. 3, no. 2, pp. 77–101, 2006.

[24] J. K. Liker and J. M. Morgan, "The Toyota Way in Services: The Case of Lean Product Development," 2006.