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Virtual Reality and Productivity in Knowledge Workers

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Productivity has a significant impact on success and monetary wellbeing of every organisation. Over the past few years, the substantial developments of digital technologies have encouraged a shift in the way we work and produce, from an office-based environment to "virtual work". However, very little is known as to how virtual work and productivity can be supported by virtual reality (VR). We conducted two studies to extend previous productivity research in relation to VR: Study one examined the routes that connect the organisational context with the individual productivity position through the lens of remote working and distributed collaboration; Study two explored the nature of and connections between productivity in individuals and teams working in VR. Based on the findings we explored how the future of VR could enact in knowledge workers' daily productivity. This was done by developing a VR productivity framework that represents physical, environmental, cognitive, and behavioural needs to ensure productivity and organisational growth. Theoretical and practical implications of the findings are discussed.

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1 INTRODUCTION

Productivity is an important factor of every organisation and has a significant impact on success and monetary wellbeing. Being "productive", traditionally, refers to the ratio between output and input (Tangen, 2002) quantified through real, tangible units, as well as by understanding the way an organisation uses resources to meet company goals (Diewert, 1992). More modern methods use proxies, by closely examining the relationship between internal (motivation) and external (office layout) factors on employees' cognitive performance, mood, and overall job satisfaction and engagement (Zhou and Shalley, 2003; Chandrasekar, 2011).

Over the past few years, substantial developments of digital technologies have encouraged a shift in the way we work and produce, from an office-based environment to "virtual work" (Wang et al., 2021). Virtual work differs from traditional work in that workers are physically dispersed, communicating, and working mostly *via* and assisted by digital technology. They, furthermore, exhibit a relationship with their employers away from a command-and-control process to more independent working, with greater control of the direction and process of tasks and executions (Watson-Manheim et al., 2002). This change in working has attracted research specifically trying to understand associations between virtual employment and productivity (Aimee, 2020), showing, at an individual level, a positive trend towards job satisfaction and self-empowerment, as well as reduced work-related expenses, and the ability to get more quality work done (Eddleston and Mulki, 2017). On a team-level, such as working in distributed virtual teams across geographical locations and/or time-zones, it has been demonstrated to lead to lower absenteeism, increased productivity, and quicker responsiveness to client needs (Lilian, 2014).

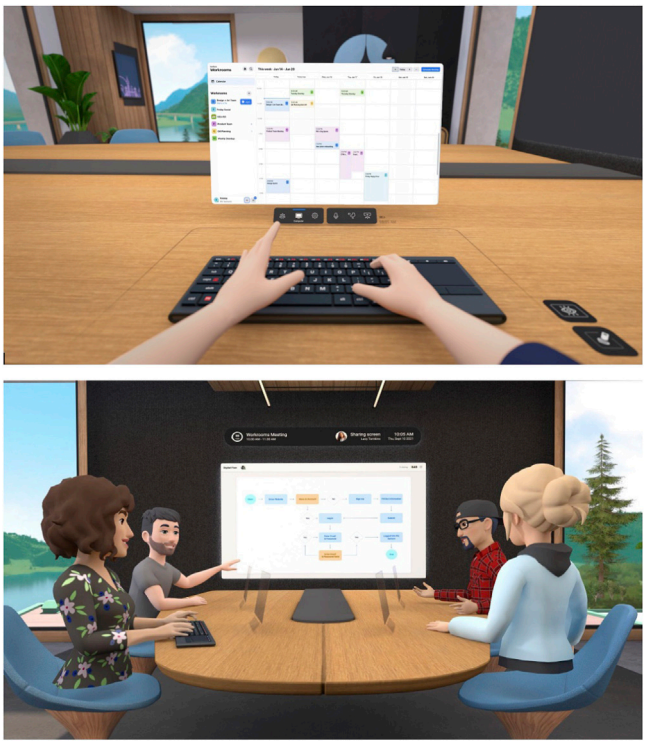

FIGURE 1 | Visuals of Horizon Workrooms Office for individual working and distributed collaboration.

Alongside virtual employment, virtual reality (VR) has been argued to provide great potential for use in work-related applications due to its unique features and flexibility (Weiss and Jessel, 1998). VR environments are usually classified as immersive environments, including interactive 3D visualisation and graphical displays, provided through a head-mounted display and handhold, position-tracked devices with one or more position trackers (Cipresso et al., 2018). It permits users to experience and interact with life-like environments, in safe and convenient times, while providing a degree of control over the simulation. Suitable work-related applications have been suggested in relation to visualisation and representation; distance communication and education; hands-on training; and orientation and navigation (Weiss and Jessel, 1998; Antonov and Hristov, 2020). Overall, findings suggest that VR has been effective for these purposes in areas such as in sports, psychology, and medicine, showing significant enhancements in technical and non-technical skills (Haluck and Krummel, 2000; Ahir et al., 2019). However, very little is known as to how VR can be used to facilitate virtual working effectively, and literature on VR specifically related to productivity is sparse.

To illustrate, research on distinctive VR features has shown that the display and manipulation of VR time and equipment such as controlling the time rate of a virtual clock (Ban et al., 2015) and keyboards of different sizes (Kim et al., 2014) can enhance productivity by increasing typing speed/accuracy and click rate, while environmental features such as the colours of the walls as well as room temperature do not create such effect (Latini et al., 2021). On a systemic level, studies have highlighted the suitability of VR especially for knowledge workers (Hansen et al., 2008)—a group of employees which represents a unique set of work characteristics, including but not limited to complex problem solving and information processing opportunities (Hernaus and Mikulic, 2014). In this context, VR is believed to enable knowledge workers to "dive into their own world of concentration through an environment that creates less distraction and more focus, compared to nowadays laptop or smartphone usage." (Li et al., 2020). However, no direct assessment of VR for productivity has been carried out, such as through ethnographic observations and/or interviews of knowledge workers having performed team and task work in VR.

In the light of the above, the aim of this study is to 1): closely examine the routes that connect the organisational context with the individual productivity position through remote working and distributed collaboration (without VR) through observations and interviews 2); explore the connections between productivity in relation to VR; and 3) demonstrate how the future of VR could enact in knowledge workers' daily productivity. The utilisation of VR for team and task work was assessed through the lens of Horizon Workrooms (WR). WR is a VR platform first released by Meta in 2021, and offers a virtual office space for traditional desktop work as well as meetings via VR telepresence, with tools such as a remote desktop and a whiteboard to 'ideate' and work on (**Figure 1**). Accessed through an Oculus headset, which is head-mounted device that provides virtual reality for the wearer, it enables users to imitate, visualise, and simulate the workplace design to the perspective of the user who uses it.

2 MATERIALS AND METHODS

2.1 Study 1: Understanding and Conceptualising Productivity in the Context of Remote Work and Distributed Collaboration

We conducted 90-min observations and interviews, respectively, with 47 knowledge workers across four countries, including Norway, Singapore, the United States, and the United States, to examine productivity in the context of remote working and distributed collaboration (without VR). Areas of interest were to understand differences of synchronous and asynchronous working, including remote individual working versus distributed collaboration; tools used for effective working; and areas of improvement and potential design implications for VR (cf. interview guide for team collaboration can be found in **Supplementary Appendix A**). Participants worked in product gaming; online media publishing; furniture; manufacturing; IT; and logistics. Company sizes ranged from 50 to 200+. All participants were active Slack, Microsoft, and Teams users, and used both desktop and mobile platforms for work activities.

2.2 Study 2: Examining Team and Individual Productivity in the Context of Virtual Reality

Study two focused on observing and discussing productivity in VR and through the utilisation of Horizon Workrooms. Thirteen knowledge workers from a large social network company, distributed over two teams (Global Policy and EMEA Data Centre), were observed during their teamwork activities (>16 h of video and audio material), taking place over a 2-month period. In addition, interviews were conducted with 25 knowledge workers using VR for teamwork, including 12 knowledge workers who executed individual productivity activities in Workrooms for at least 30 min once a week over the past 2 months (cf. interview guide for individual productivity in VR in **Supplementary Appendix B**). Participants were distributed across three locations, including the United States, the United States, and Ireland, and worked across fields, including engineering, operations, legal, data science, and business.

Ethical approval was sought and obtained by Meta's Ethical Research Authority before the data collection started. Written consent was obtained from all participants.

2.3 Data Processing

The data was transcribed verbatim by an external company for an agreed fee. Both observational and interview data were analysed using a framework analysis and journey mapping was executed where possible. The framework analysis is a method/technique first used in the 1980s to analyse large-scale social policy research (Ritchie and Lewis, 2003; Gale et al., 2013). Similar to content analyses, the first steps are to transcribe data, followed by familiarisation with the interview and coding of the data. In this study, both the audio and video recordings of the observations and interviews were transcribed verbatim (word for word), and audio recordings and transcripts read multiple times, before initial contextual or reflective notes, such as analytical notes, thoughts, and impressions were formulated by the researchers. After the familiarisation, the researchers conducted a mixture of inductive and deductive "open coding" of the data line-by-line. The deductive/inductive approach helps to code data by not only having pre-defined areas of interest for this study, but also to ensure that important aspects of the data that were not considered are not missed. Open coding refers to anything that may be relevant in relation to VR and productivity. This could be related to behaviours, values, including beliefs of how VR can support/hinder productivity, emotions (e.g. frustrations by missing aspects of the VR environment to support productivity). Example quotes of extracted codes are provided throughout the manuscript, and participants were numbered to ensure anonymity. Once the coding was done, a working analytical framework was developed, by discussions of initially developed codes from each researcher being grouped into clearly defined categories. The framework was then applied by indexing subsequent transcripts using the existing codes and categories, before being charted into a framework matrix. Charting involves summarising the data by category from each transcript, which can then be used as a supporting feature in exploring interesting ideas/concepts/themes that highlight (a) characteristics of and differences between the data; (b) theoretical concepts (either prior concepts or ones emerging from the data); or (c) mapping connections between categories to explore relationships and/or causality. This allowed the authors to understand and predict how participants may respond to VR for productivity, and to identify areas that could be enhanced as part of the VR office concept.

3 RESULTS

By drawing on the findings, we developed a productivity framework in relation to virtual work, productivity, and VR. First, we examined the routes that connect the organisational context with the individual productivity position through the lens of remote working and distributed collaboration; second, we explored the nature of and connections between productivity in individuals and teams working in VR and demonstrated how the future of VR could enact in knowledge workers' daily productivity. **Tables 1** and **2** provide an example of the codes and exemplar quotes; **Figure 2** a journey mapping of remote working and distributed collaboration; **Figure 3** depicts a VR productivity framework developed from the findings, and which is supported by existing productivity framework in non-VR related fields (Haynes, 2007). This was done by mapping connections between categories and to explore relationships.

3.1 Study 1: Understanding and Conceptualising Productivity in the Context of Remote Work and Distributed Collaboration

3.1.1 Virtual Work: Conceptualisation

Findings from the observations showed that virtual work was characterized by *transparency*; *distributed connection; and responsiveness.* All three were reflected in the need of synchronous and asynchronous collaboration and visibility to team members' *availability* and working progress, through information sharing and exchange and simultaneous task management and execution. Synchronous collaboration was mostly conducted when high-stake decisions were made, content or projects were in the initial stage of developments, and when tasks were yet to be delegated and responsibilities distributed. In contrast, asynchronous working was observed when projects were already formulated and defined through clear ownership and associated experience (cf. **Figure 2**). *Individual work and productivity*, mainly executed during asynchronous working, were defined by participants working on single, focused tasks activities, such as programming codes or preparing and reviewing documents. Ideally, they were executed in a certain state of mind, i.e. "in the zone" (Csikszentmihalyi, 1990), in order to achieve high-quality work. *Collaborative work and productivity* were reflected in multi-tasking, which, depending on the nature of the role, meant executing tasks with multiple objectives at the same time; coordinating projects; and managing people. Collaborative productivity was, furthermore, shaped by: (a) external monitoring and validation by, for instance, managers;

TABLE 1 | Virtual working conceptualisation: Codes and example quotes.

Codes	Example Quotes
Productivity	"[. . .] if I do something quickly, but it's not quality work, then it's also not productive. For me, those two things must come together." (#5)
Single tasks versus multi-tasking	"Single tasks are report writing or writing code, brainstorming and kicking around ideas, reviewing and working on documents, or preparing for a presentation." (#1,3,5) "Multi-tasking is reflected in different tasks, [with] different objectives [and the] switch between them, whilst aiming for one focus." (#5)
Task prioritisation and monitoring	"If I get to the end of a session and I've done what I set out to do, [...] by reducing the number of "one, two, three, four [. . .] priorities for the day or for the week' [and gauging whether I am] ahead of schedule or behind track" (#5).
Availability	"I might [want] to be available for my direct report or manager, but not for others" (#14) "I might be available for something more serious or important - or more fun - than what I am currently doing." (#25). "[. . .] especially at a certain point in the day, about 4:00 p.m. is when all my colleagues wake up, things are going to get busy, [which] can be a bit of a nightmare for [individual] productivity" (#1).
Notification management	"I have recently caught myself working on something and then a notification pops up. I click on it and then I am actually far removed from my work task, and I am just responding to people. It is definitely a distraction." (#21). "[...] having the ability to mute conversations or unmute conversations [...] really helps [to] stay productive and focus." (#2) "Focus blocks [on one's calendar] turns off all your notifications [which] helps reduce multitasking [and] reducing the number of pings I'm getting." (#4)

and (b) shared task responsibilities with team members working in different time zones.

3.1.2 Virtual Work: Productivity Tools

Remote workers usually utilised tools that were *cloud-based and collaboration focused*, including Office 365, WhatsApp, Messenger, or Zoom. Inherent of each tool was the desire of users to make collaboration easier and more efficient, including *fewer meetings and calls*, through greater asynchronous communication, and *less reliance on a single ownership* as well as *reduced feedback processes*, by enabling multi-party access and responsibility distribution for content creation and review. Tools were further highlighted to maintain productivity through *productivity prioritisation* and *monitoring*, respectively, which involved a decision-making process based on focus adjustments in relation to task urgencies and deadlines. Prioritisation and monitoring occurred at both individual and team level—internally (e.g. anxiety, motivation) and externally (e.g. project deadline)—driving the direction and process of task execution. Tasks priorities were monitored by the types of set goals; the reduction of the number of priorities for the day and week, respectively, both of which were usually tracked through tools such as OneNote or Post-It notes; and whether tasks were ahead of schedule or behind track.

3.1.3 Virtual Work: Availability and Notification Management

Observations have also shown that current indications of team members availability and notifications was a poor proxy for presence, and that current tools did not reflect the layers of social complexity around one's perception of how a person saw one's own availability to others. In particular, priorities around availability were dynamic and dependent on who a knowledge worker wanted to be available for, as well as what tasks they wanted to be available for. Furthermore, notifications of availability were observed to be too simplistic; while notification management was often used for focused productivity time or the ability to execute 'undisrupted' communication with team members during collaboration activities, they did not offer smart filtering, such as appropriate timing based on one's degree of workload, feedback on who the notification is from, or how important or urgent the notification was for the knowledge worker. This, alongside a constant feeling of 'having to be available', has shown that notifications could create a significant interruption to one's productivity.

3.2 Study 2: Examining Individual and Teamwork and Productivity in the Context of Virtual Reality

Study one focused on the conceptualisation of productivity and work in the context of remote working and distributed collaboration. With this in mind, study two investigated remote working and distributed collaboration in the context of VR, and how VR can enact in knowledge workers' daily productivity. The latter was done by highlighting opportunities, challenges, and implications for future VR developments (cf. **Figure 3**).

3.2.1 Individual Work and Virtual Reality

Participants' reasons for participating in VR for individual productivity was the opportunity to have a private space, a personal desk, and the physical separation from one's home environment. All three created the feeling of "being somewhere else", without distractions. They also appreciated the level of immersion VR offered them, with an 'infinite' space at their disposal, as well as the ability to shut out external distractions. Through the headset a physical separation between their external environment was created,

TABLE 2 | VR and productivity: Codes and example quotes.

Codes	Example quotes
Productivity in VR	"You block out your phone and block out your computer when you are in Workrooms, maybe because of that physical barrier that you put between yourself and the outside world, by the very definition of wearing the headset" (#1)
Challenges of VR for individual and teamwork, including: 1. Headset weight 2. Customisation needs 3. Safety 4. Note taking 5. Avatar	1. "After an hour and a half, [. . .] the headset, itself, got a little uncomfortable (#1, 21)" 2. "Break rooms, and maybe you can walk around and find people and you meet [and talk] there." (# 3, 26) 3. "I might try to move my laptop or try to reposition myself, but oh, there's actually nothing, there's no desk over there [. . .] maybe there should be a warning when for example, oh, there's actually nothing here." (#2) 4. "Any meeting where we would brainstorm, I don't know how we would do it in VR because you can't take notes very easily" (#17) 5. "What one sees in a video call, you can't really do that in VR, because you don't see the facial expressions" (#18)
Presence in VR	Even that you have avatars, it feels like you are together... feels like you are standing in the same room and looking at the same things... it's like you feel more connected, you feel more within the room, you don't have Jennifer on the screen, you have her in the room... it's valuable to just be there (#25)
Equal voice and inclusion in VR	...everybody felt like they were in the same space and we interacted much, much better than doing it in a normal setting... everybody was treated equally and felt like they had an equal voice... it made it better (#22) Voice mail and email and texts are very one dimensional and don't give you context or tone...But even in VR, the way you hold your hands and the tone of your voice, really adds color to the conversation and it has helped relationships between our team... People start behaving in a way that they feel more included and part of the team. (#19)
Perception of shared space in VR and why it matters 1. Shared screen 2. Shared point of view 3. More engaged meetings 4. Experiencing moments together 5. Performing one's personality	1. "We found the functionality of sharing the screen very, very helpful for us... Especially explaining in details on a small screen with 700 racks on it was difficult as we talk sometimes about a single rack. So in VR I could just point at that [rack]and then draw over it." (#18) 2. "Okay, now I know this tool. Now I can work with it"...We chose VR because he could point out... he was circling all the items that he didn't know, and he wanted to hear more about. That was a super valuable VR session." (#25) 3. "It added a little spice to our meetings because people were very happy about using the headsets, and they were cheerful and... usually the meetings were, I don't want to say boring, but they were very slow.... But, here with the avatars, people had fun in it. It felt like we were playing all the time, but we were not." (#12) 4. The most memorable is definitely when we fell through the floor... Our team bonded overtechnical difficulties... when we first logged on, all of our skin tones and hair colors were totally weird. So we had to have those conversations, which is not a conversation you typically have with a coworker. In a weird way, the technical difficulties helped to break down barriers that may have existed. (#16) 5. It is very to character that [manager] has chosen this queen headdress to wear. We are all like, "She's the boss." And I think those kind of things are fun. There's definitely ways that you're bringing your personality into a virtual reality situation because you're trying to emulate yourself. They give away parts of you that you want people to know, and that's I think been good for team cohesiveness. (#13)

enabling productivity through the mental state they wished to achieve in VR.

Expressed constraints of VR for individual work were mentioned in relation to the *physical setup and environmental needs*; and the *tools needed to be productive*. Physical setup and environmental needs in VR were: lighter hardware weight, longer battery life, and better comfort, allowing to utilise VR for prolonged amount of time; personalised work space by having pens, papers, and a picture of the family on their virtual desk, as well as the ability to change environmental features such as a beach with ocean noises, coffee-house environments, chirping birds, or calming background music as a way to relax; the ability to move around and interact with the VR space itself, such as going to the window for a break, or by changing venues to allow for interaction with others; and safety concerns, by not knowing where the real space ends and the VR space begins.

Participants, furthermore, expressed the importance of work, health- and well-being tool integrations. Work tools included an enhanced ability to interact with and draw on the whiteboard, for individual and team activities, as well as smaller, multiple groups; multiple monitors to execute different tasks; task monitoring and meeting tracking tools such as calendars; and, a timer that enables participants to increase productivity and mindfulness of the time spent in VR. Health and well-being tools were mentioned in relation to having background music or

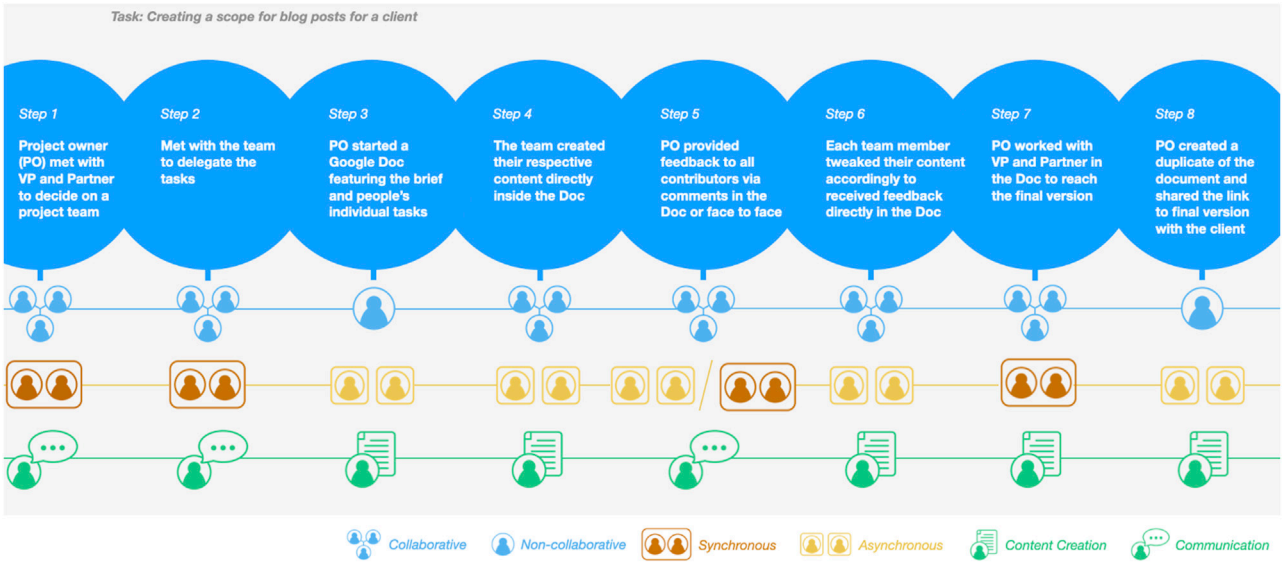

FIGURE 2 | Example of Individual and collaborative work patterns (synchronous and asynchronous) from the early to the late stage of a project. Both individual and collaborative work activities are displayed.

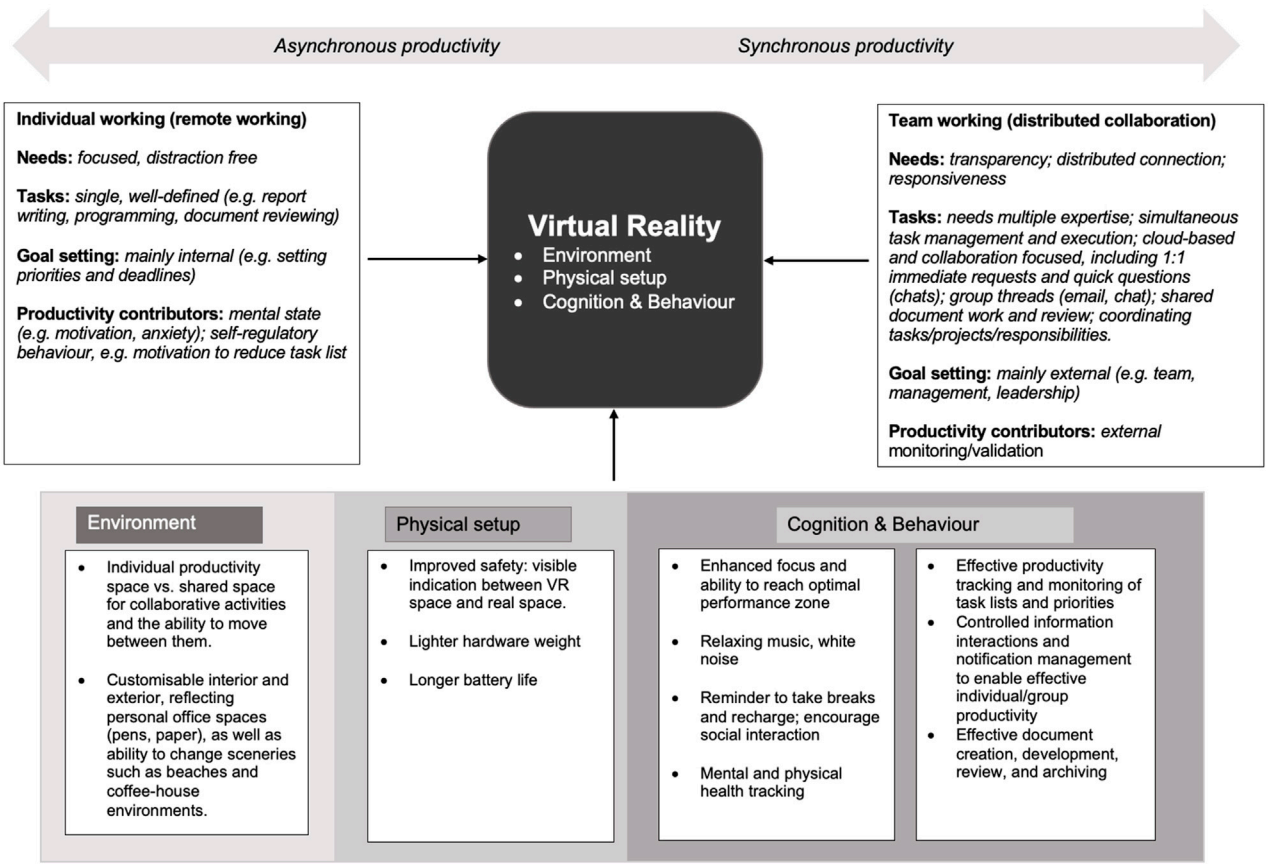

FIGURE 3 | Individual/team productivity in VR, consisting of environmental, physical, cognitive, and behavioural considerations.

white noise to enhance one's focus; reduced notifications to permit distractions and the risk of multi-tasking; breaks, either by creating opportunities for (non-) work-related interactions with colleagues or alone; and taking part in meditation or stretching activities, provided through tailored notifications in VR.

3.2.2 Teamwork and Virtual Reality

Benefits of working in VR was the ability of sharing an office space, enhanced perceptions of joyful, energised teamwork sessions, and an equal feeling of presence and voice. Findings showed that shared space mattered, because it supported teams to align on task and project content, direction, and progress, and enabled sharing content that was visible for everyone, while not losing sight of the person in the room. As such, participants were more engaged with the work as well as one another. Creating personalised avatars meant for participants to share aspects of their personality by emulating themselves through their virtual representation, which participants perceived as a significant contributor to team cohesiveness. Over the course of 2 months, participants expressed and exhibited a feeling of pro-active involvement, team inclusion, social presence (Greenwald et al., 2017), as well as the ability to mutually influence on another (Carson et al., 2007). Overall, it was expressed that VR supports team collaboration by helping team members to align on the same content, but in a better setup (cf. **Table 2** for examples).

Challenges and opportunities for VR and teamwork were emphasised by (a) reduced hardware weight and better comfort; (b) enhanced ability of note taking and modification; (c) greater multi-tasking—ideally, by having multiple screens for different purposes, such as screens for sharing, searching for content, taking notes, etc.; (d) better facial expressions of avatars, and a stronger representation of workers' physical appearance, including clothing and accessories. Lastly, future usage of VR for collaboration was dependent on the ability to allow for VR customization, such as by having break-out rooms for smaller teamwork activities and discussions.

4 DISCUSSION

Investigating how knowledge workers conceptualise virtual work including individual and team productivity is important to understand how VR's current productivity (tool) design can be enhanced and benefit a range of different activities (Kim et al., 2019). The aim of this study was two-fold: Study one examined the routes that connect the organisational context with the individual productivity position through the lens of remote working and distributed collaboration; Study two explored the nature of and connections between productivity in individuals and teams working in VR. Based on the findings we explored how the future of VR could enact in knowledge workers' daily productivity. This was done by developing a VR productivity framework that represents physical, environmental, cognitive, and behavioural needs to ensure productivity and organisational growth (cf. **Figure 3** for an overview). In addition, we provide the following theoretical and practical implications:

Firstly, findings from study one showed that productivity is a multifaceted concept, which, in line with Kim et al. (2019) (Kim et al., 2019), was largely determined by perceived efficiency and quality of work, set by deadlines, and monitoring that was self-imposed; knowledge workers' mental state (e.g. attention, motivation, tasks satisfaction); type of task (single tasks versus multi-tasking); and self-regulation behaviour (e.g., task tracking versus external validation). In addition, we explored productivity within the organisational context, which shaped and impacted the need of synchronous and asynchronous collaboration and visibility to team members' *availability* and working progress, through effective and efficient information sharing and exchange, as well as simultaneous project management and execution.

Previous research has shown that productivity is mediated by knowledge workers' engagement and self-regulatory behaviour, both of which have significant impact towards creating organisational growth (Stander et al., 2014). Work engagement is defined as a 'positive, fulfilling, work-related state of mind characterised by vigour, dedication, and absorption' (Schaufeli and Bakker, 2004), including aspects such as positive affect and energy, psychological involvement in one's role, as well as psychological flow (van Woerkom et al., 2016). Self-regulation, which is the ability to control one's behaviour, emotions, and thoughts helps to continuously engage in the direction, intensity, and persistence of effort, with the goal to strive for internal representations of their desired end states, such as collaborative task achievements (Austin and Vancouver, 1996; Vancouver, 2008).

Navigating to the point when these end states are accomplished depend on the feedback loop they receive, enabling a comparison between personal and externally validated performance, and taking corrective actions if discrepancies arise. For this to happen, developing realistic perceptions on goal progresses and velocity, which is the rate to which these goals are achieved, matter (Johnson et al., 2013). This requires effective *time management planning*, such as task lists, prioritising tasks, and determining how and when to perform them, as well as *contingent planning*, in which employees anticipate possible interruptions in their work and plan for them, as a mechanism to stay engaged, on track, and perform well.

Our findings are in alignment with the above, showing a positive association between time management, contingency planning, and productivity; as well as conditional effect between effective time management and the number but also type of interruptions throughout the day. Sentiments towards interruptions were dependent on its nature, such as impromptu interactions for problem-solving or learning activities, or scheduled meetings to maintain organisational productivity. These were perceived less affecting compared to *distractions*, which were described as interfering stimuli one wished to ignore, such as the exposure to work-irrelevant conversations through notifications coming from, for instance, online chats including Workplace or Microsoft Teams.

Results from study two showed that VR positively contributed to a perceived productivity and overall quality, by providing a distraction-free and focused work environment; and the

perception of a shared office space that created joyful, energised teamworking, and an equal feeling of social presence and pro-active involvement.

Research has shown that equal abilities to contribute to team activities increases effective team performance (Driskell and Salas, 1992; Butchibabu et al., 2016) by providing a strong sense of camaraderie, support and participation, which, in turn, elevates individuals' work cooperation, and the development of shared responsibilities for team outcomes (Elsaied, 2018). It furthermore supports members to ask questions, seek help, report mistakes and raise concerns without having to fear negative consequences as a result of their behaviour (i.e. psychological safety; (Edmondson, 1999)). In contrast, social presence, although dependent on various factors such as the type of task, quality of avatars, level of interactivity, haptic feedback, etc., has been associated with a greater perception of trust in team members and perceived usefulness of team activities (Oh et al., 2018). Future research should therefore investigate how VR exactly shapes such group behaviour and perception, by acknowledging individual roles, and the multilevel linking mechanism between individual traits and team outcomes via psychological and social processes (Stewart et al., 2005). This will help identify predictors at individual and team level on an individual-level outcome, and the moderating effects of team level variables on relationships between individual-level variables (Oh et al., 2018), including aspects such as shared leadership (Carson et al., 2007), psychological safety (Edmondson, 1999), task, interpersonal and process conflicts (Jehn and Mannix, 2001), as well as an adaptive cooperative attitude—all assessed in the context of VR. By providing an environment that encourages individuals to both manage and develop within a team; team bonding through active involvement and emotional support; and that offers avatars for an enhanced feeling of social presence, VR has the potential to achieve enhanced productivity through greater individual expressivity and commitment, and active participation in decision making.

4.1 Implications for Future Virtual Reality Applications

Because both individual and team productivity are needed to ensure organisational success, future developments in VR office spaces are advised to find the right balance between overall (individual) productivity and the complexity, duration, timing, and frequency of collaborative activities throughout the day. This includes 1) easily accessible, usable, and safe hardware and software applications; 2); customisable room configurations (e.g. personalised versus team working space); and 3) productivity enhancing role- and team-dependent work tools, including prioritisation and monitoring applications that use smart filtering suitable for the nature and content of the task activity (e.g. synchronous and asynchronous work, brainstorming, etc.).

For the latter, VR applications, in particular, need to address challenges that are inherent in current organisational productivity paradigms, which requires ad-hoc availability for information interaction and exchange, by attending team meetings and engaging in (synchronous and asynchronous) activities such as planning, delegating, and sharing tasks and information. Such working creates the risk of content fragmentation and lack of clear ownership, which, in this study, was observed by teams operating on numerous 'living' documents of different formats, and an enhanced need for content tracking and archiving. Multiple ownerships caused conflicts and discomfort in relation to the quality of content output and project accountability, with tools not being able to account for nuances and changes in ownerships over time. Considering these needs alongside adequate time management and contingent management plans to be productive, future VR applications will need to be tested via e.g. simulated series of predetermined work activities; productivity success measures (e.g. efficiency); perceived effectiveness of the simulated workplace; and, a validation of the designed features through e.g. Multi Criteria Decision Making, in order to establish the order of preference in selecting the best option among many alternatives based on the desired productivity outcome (Muttaqin et al., 2020).

4.2 Limitations and Further Research

While this study is one of the first to assess the concept of productivity in the context of VR, the following limitations are worth mentioning:

This study was conducted with a diverse sample using qualitative methods to understand productivity in VR. Future studies are encouraged to investigate productivity in VR with a larger sample of similar professional background, using a mixed methods methodology including objective performance markers as well as productivity behaviour to assess the value of VR for teamwork and task work, and by directly comparing the VR productivity to real life activities.

We explored team and task work using a specific VR application, namely Horizon Workrooms. Using this platform to explore productivity may have limited participants' views on opportunities and constraints experienced in VR. Future studies are, therefore, advised to either collect data on productivity using a variety of platforms, or by exploring productivity in VR more broadly, to allow for more generalizable interpretations of results in the context of VR.

While we observed teams in VR over a period of 2 months, future studies are encouraged to develop a longitudinal study that robustly tracks user sentiment data, where changes of perceptions, effectiveness, and usefulness of VR for work and productivity are recorded over a longer period. This will help overcome the risk of biased assessments, and to design a VR space that has been design iteratively, with user perceptions in mind.

Our framework offers first insights into how productivity can be supported through VR, through the lens of Meta's Workrooms; however, future studies are advised to carry out further validations, continuing to revise and adapt content depending on the nature of the productivity tasks and work profession, as well as by examining the causal relationship between productivity themes (e.g. transactional knowledge, concentrated study, group processes versus individual processes) and productivity evaluation, such as

the relationship between the worker's state and the productivity in VR.

Lastly, we wish to acknowledge the limitations of current technologies itself. For instance, the vergence-accommodation conflict remains a cause for eye fatigue and discomfort for both virtual and augmented reality applications (Hoffman et al., 2008; Kramida, 2016). These constraints limit the ability of users to engage full-time in teamwork and task work using VR, and, as such, does not offer a replacement to other online productivity and collaboration tools. Instead, it represents an additional means to engage oneself in individual taskwork and collaboration activities, respectively, through immersive three-dimensional surroundings and content display. Future studies who apply VR for work will have to explore these health and safety implications in greater detail, and design and execute policies that support users in the appropriate use of VR for productivity.

5 CONCLUSION

This research has determined a range of factors that may be helpful for individual and teamwork and productivity conceptualisation within the virtual environment. Future studies are advised to further explore the need of planning and productivity tools using smart technology such as artificial intelligence to ensure optimised and individually tailored productivity within VR. Ideally, this will be achieved by a better awareness of goal-discrepancy induced task pressures and urgencies, and the environmental, cognitive, and behavioural needs of VR to help increase work engagement and overall productivity accomplishment (Parke et al., 2017).

DATA AVAILABILITY STATEMENT

The datasets presented in this article are not readily available because of data privacy polices at Meta.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Meta Ethical Research Authority. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

LA: Conceptualisation, Methodology, Investigation, Data Curation, Formal analysis, Writing—Original Draft, Writing—Review and Editing, NE-D: Conceptualisation, Methodology, Investigation, Data Curation, Formal analysis, Writing—Review & Editing.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/frvir.2022.890700/full#supplementary-material

REFERENCES

Ahir, K., Govani, K., Gajera, R., and Shah, M. (2019). Application on Virtual Reality for Enhanced Education Learning, Military Training and Sports. *Augment. Hum. Res.* 1 (5), 1–9. doi:10.1007/s41133-019-0025-2

Aimee, C. S. (2020). *Relationship between Virtual Employee Engagement, Self-Efficacy, and Productivity*. Minneapolis, MN, United States: Walden University.

Antonov, S. I., and Hristov, H. A. (2020). Increasing Productivity with the Combined Use of CAD/CAM/CAE Software Platforms for Collective Work during the Design of the Multipurpose Training-Practice Mortar Round for Short Distance Engagements. *Int. Conf. Knowl-BASED Organ.* 26 (3), 1–7. doi:10.2478/kbo-2020-0106

Austin, J. T., and Vancouver, J. B. (1996). Goal Constructs in Psychology: Structure, Process, and Content. *Psychol. Bull.* 120 (3), 338–375. doi:10.1037/0033-2909.120.3.338

Ban, Y., Sakurai, S., Narumi, T., Tanikawa, T., and Hirose, M. (2015). "Improving Work Productivity by Controlling the Time Rate Displayed by the Virtual Clock," in Proceedings of the 6th Augmented Human International Conference, New York, NY, United States, 9 March 2015, 25–32. doi:10.1145/2735711.2735791

Butchibabu, A., Sparano-Huiban, C., Sonenberg, L., and Shah, J. (2016). Implicit Coordination Strategies for Effective Team Communication. *Hum. Factors* 58 (4), 595–610. doi:10.1177/0018720816639712

Carson, J. B., Tesluk, P. E., and Marrone, J. A. (2007). Shared Leadership in Teams: An Investigation of Antecedent Conditions and Performance. *Amj* 50, 1217–1234. doi:10.5465/amj.2007.20159921

Chandrasekar, K. (2011). Workplace Environment and its Impact on Organisational Performance in Public Sector Organisations. *Int. J. Enterp. Comput. Bus. Syst.* 1 (1), 1–19.

Cipresso, P., Giglioli, I. A. C., Raya, M. A., and Riva, G. (2018). The Past, Present, and Future of Virtual and Augmented Reality Research: A Network and Cluster Analysis of the Literature. Available from: https://www.frontiersin.org/article/10.3389/fpsyg.2018.02086.

Csikszentmihalyi, M. (1990). *Flow: The Psychology of Optimal Experience*. New York, NY: Harper & Row.

Diewert, W. E. (1992). The Measurement of Productivity. *Bull Econ. Res.* 44 (3), 163–198. doi:10.1111/j.1467-8586.1992.tb00542.x

Driskell, J. E., and Salas, E. (1992). Collective Behavior and Team Performance. *Hum. Factors* 34 (3), 277–288. doi:10.1177/001872089203400303

Eddleston, K. A., and Mulki, J. (2017). Toward Understanding Remote Workers' Management of Work-Family Boundaries: The Complexity of Workplace

Embeddedness. *Group & Organ. Manag.* 42 (3), 346–387. doi:10.1177/1059601115619548

Edmondson, A. (1999). Psychological Safety and Learning Behavior in Work Teams. *Adm. Sci. Q.* 44 (2), 350–383. doi:10.2307/2666999

Elsaied, M. M. (2018). Supportive Leadership, Proactive Personality and Employee Voice Behavior: The Mediating Role of Psychological Safety. *Am. J. Bus.* 34 (1), 2–18.

Gale, N. K., Heath, G., Cameron, E., Rashid, S., and Redwood, S. (2013). Using the Framework Method for the Analysis of Qualitative Data in Multi-Disciplinary Health Research. *BMC Med. Res. Methodol.* 13 (1), 117. doi:10.1186/1471-2288-13-117

Greenwald, S. W., Wang, Z., Funk, M., and Maes, P. (2017). Investigating Social Presence and Communication with Embodied Avatars in Room-Scale Virtual Reality. *Commun. Comput. Inf. Sci.* 725, 75–90. doi:10.1007/978-3-319-60633-0_7

Haluck, R. S., and Krummel, T. M. (2000). Computers and Virtual Reality for Surgical Education in the 21st Century. *Arch. Surg.* 135 (7), 786–792. doi:10.1001/archsurg.135.7.786

Haynes, B. P. (2007). Office Productivity: A Theoretical Framework. *J. Corp. Real Estate* 9, 97–110. doi:10.1108/14630010710828108

Hernaus, T., and Mikulic, J. (2014). Work Characteristics and Work Performance of Knowledge Workers. *EuroMed J. Bus.* 9, 54. doi:10.1108/emjb-11-2013-0054

Hoffman, D. M., Girshick, A. R., Akeley, K., and Banks, M. S. (2008). Vergence-accommodation Conflicts Hinder Visual Performance and Cause Visual Fatigue. *J. Vis.* 8 (3), 33. doi:10.1167/8.3.33

Jehn, K. A., and Mannix, E. A. (2001). The Dynamic Nature of Conflict: A Longitudinal Study of Intragroup Conflict and Group Performance. *Amj* 44 (2), 238–251. doi:10.5465/3069453

Johnson, R. E., Howe, M., and Chang, C.-H. (2013). The Importance of Velocity, or Why Speed May Matter More Than Distance. *Organ. Psychol. Rev.* 3 (1), 62–85. doi:10.1177/2041386612463836

Kim, J. H., Aulck, L., Thamsuwan, O., Bartha, M. C., and Johnson, P. W. (2014). The Effect of Key Size of Touch Screen Virtual Keyboards on Productivity, Usability, and Typing Biomechanics. *Hum. Factors* 56 (7), 1235–1248. doi:10.1177/0018720814531784

Kim, Y.-H., Choe, E. K., Lee, B., and Seo, J. (2019). "Understanding Personal Productivity," in Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems, New York, NY, USA (Association for Computing Machinery), 1–12. doi:10.1145/3290605.3300845

Kramida, G. (2016). Resolving the Vergence-Accommodation Conflict in Head-Mounted Displays. *IEEE Trans. Vis. Comput. Graph.* 22 (7), 1912–1931. doi:10.1109/tvcg.2015.2473855

Latini, A., Di Giuseppe, E., D'Orazio, M., and Di Perna, C. (2021). Exploring the Use of Immersive Virtual Reality to Assess Occupants' Productivity and Comfort in Workplaces: An Experimental Study on the Role of Walls Colour. *Energy Build.* 253, 111508. doi:10.1016/j.enbuild.2021.111508

Li, J., George, C., Ngao, A., Holländer, K., Mayer, S., and Butz, A. (2020). "An Exploration of Users' Thoughts on Rear-Seat Productivity in Virtual Reality," in 12th International Conference on Automotive User Interfaces and Interactive Vehicular Applications, Virtual Event DC USA (ACM), 92–95. Available from:. doi:10.1145/3409251.3411732https://dl.acm.org/10.1145/3409251.3411732

Lilian, S. C. (2014). Virtual Teams: Opportunities and Challenges for E-Leaders. *Procedia - Soc. Behav. Sci.* 110, 1251–1261. doi:10.1016/j.sbspro.2013.12.972

Muttaqin, B. I. A., Prastyabudi, W., and Zunaidi, R. (2020). Workplace Design Selection Framework to Increase Productivity by Using Virtual Reality. *AIP Conf. Proc.* 2217 (1), 030118. doi:10.1063/5.0000641

Oh, C. S., Bailenson, J. N., and Welch, G. F. (2018). *A Systematic Review of Social Presence: Definition, Antecedents, and Implications*. Front Robot AI. Available from: https://www.frontiersin.org/article/10.3389/frobt.2018.00114.

Parke, M., Weinhardt, J., Brodsky, A., Tangirala, S., and DeVoe, S. (2017). When Daily Planning Improves Employee Performance: The Importance of Planning Type, Engagement, and Interruptions. *J. Appl. Psychol.* 103 (3), 300–312. doi:10.1037/apl0000278

Ritchie, J., and Lewis, J. (2003). *Qualitative Research Practice: A Guide for Social Science Students and Researchers*. London, UK: SAGE Publications Ltd, 353.

Schaufeli, W. B., and Bakker, A. B. (2004). Job Demands, Job Resources, and Their Relationship with Burnout and Engagement: A Multi-Sample Study. *J. Organiz. Behav.* 25 (3), 293–315. doi:10.1002/job.248

Stander, F. W., Mostert, K., and de Beer, L. T. (2014). Organisational and Individual Strengths Use as Predictors of Engagement and Productivity. *J. Psychol. Afr.* 24, 403–409. doi:10.1080/14330237.2014.997007

Stewart, G. L., Fulmer, I. S., and Barrick, M. R. (2005). An Exploration of Member Roles as a Multilevel Linking Mechanism for Individual Traits and Team Outcomes. *Pers. Psychol.* 58, 343–365. doi:10.1111/j.1744-6570.2005.00480.x

Tangen, S. (2002). "Understanding the Concept of Productivity," in Proceedings of the 7th Asia-Pacific Industrial Engineering and Management Systems Conference, Taipei, 18–20.

van Woerkom, M., Oerlemans, W., and Bakker, A. B. (2016). Strengths Use and Work Engagement: a Weekly Diary Study. *Eur. J. Work Organ. Psychol.* 25 (3), 384–397. doi:10.1080/1359432x.2015.1089862

Vancouver, J. B. (2008). Integrating Self-Regulation Theories of Work Motivation into a Dynamic Process Theory. *Hum. Resour. Manag. Rev.* 18 (1), 1–18. doi:10.1016/j.hrmr.2008.02.001

Wang, B., Liu, Y., Qian, J., and Parker, S. K. (2021). Achieving Effective Remote Working during the COVID-19 Pandemic: A Work Design Perspective. *Appl. Psychol.* 70 (1), 16–59. doi:10.1111/apps.12290

Watson-Manheim, M., Chudoba, K., and Crowston, K. (2002). Discontinuities and Continuities: A New Way to Understand Virtual Work. *IT People* 15, 191–209. doi:10.1108/09593840210444746

Weiss, P. L., and Jessel, A. S. (1998). Virtual Reality Applications to Work. *Work Read. Mass* 11 (3), 277–293. doi:10.3233/wor-1998-11305

Zhou, J., and Shalley, C. E. (2003). Research on Employee Creativity: A Critical Review and Directions for Future Research. *Res. personnel Hum. Resour. Manag.* 22, 165–217. doi:10.1016/S0742-7301(03)22004-1

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