THEME ARTICLE: FUTURE OF WORK

The Nomadic Office: A Location Independent Workspace Through Mixed Reality

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The worldwide spread of the coronavirus forcefully affected our lives, the economy, and social culture. Unforeseen, a significant number of workforces are requested or required to work from home, impacting creativity, work performance, and social interaction. Video conferencing tools are consequently substituting in-person meetings; new workplaces are arranged in domestic environments, causing a shift in how employees work and interact with their environment. At the same time, recent developments in mixed reality (MR) enable us to synthesize virtual office environments and experience them on the go. This article consolidates how the latest research in MR supports the transition of desktop computing into the virtual realm, enriching traditional office environments with virtual elements. We conceptualize augmented domestic workspaces and truly nomadic offices that overcome the physical constraints and unfavorable effects of continuous telecommuting. To promote future research, we highlight open research questions and outline a nomadic MR office of the future.

The worldwide spread of the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) resulted in curfews, quarantines, lockdowns, or similar restrictions in many countries. The pandemic is vigorously affecting our everyday life and a large number of industry sectors. While systemically relevant industries such as energy, communication, essential services, and particularly healthcare, continue working on-site, other businesses transition a significant number of workforces to work from home as an alternative. Even worse, governments forced businesses such as gastronomy, congress, or event organization to temporarily suspend their operations, resulting in unemployment or reduced working hours.

The opportunities and challenges introduced by telecommuting are widely discussed;[8] however, never before so many employees were asked to permanently work remotely on such short notice. For most knowledge workers, such as programmers, technical writers, or engineers, this transition seems uncomplicated in the first place since their workspace can be decentralized from their provided workspace. Furthermore, telecommuting can increase the employee's satisfaction and personal work balance due to reduced travel time and commuting stress.[2] Nevertheless, it introduced several limitations for employers and employees. For example, the work environment and its associated social setting is limited to meetings in virtual spaces. Users are exposed to privacy and security issues that can result from remote connections. Furthermore, workers are susceptible to spend more working hours on their tasks since the boundaries between work and home environments overlap significantly. Finally, working from home offers a number of additional distractions such as household chores, or require to take care of close relatives (e.g., children). Ultimately, telecommuting can drain innovation and individual creativity.[21] Often, moments of creativity are sparked between meetings and during chats in corridors or cafe kitchens. The elimination of these situations hinders individual performances in creativity and overall innovation.

The prevailing pandemic changes traditional telecommuting in the sense that the isolation is permanent

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all week long. Today, the SARS-CoV-2 forced us to attend meetings, conferences, and collaboration in a digital realm. According to a recent survey, the pandemic accelerated the digital transformation of businesses and digitally enabled products by up to seven years. However, the many of these changes are likely to remain even after the pandemic.[13] These include particularly remote working and collaboration. Thus, prolific spaces for work that face the challenges of a home workspace or popup spaces where the entire spectrum of devices for personal work are not accessible are gaining importance.

In this article, we discuss the vision of a mixed reality (MR) enhanced nomadic office including the challenges and potential solutions established by shifting telecommuting toward an MR experience. We highlight the novel interaction aspects MR can offer, including the ability to augment existing physical office environments, provide a productive environment on-the-go (e.g., by creating a hybrid multiscreen environment in a wearable headset that users can take everywhere), and to enter text efficiently. We survey existing concepts of nomadic offices and reflect on our proof-of-concept implementation and accompanied user study as a foundation of future MR offices. We specifically highlight the feasibility and flexibility of MR environments for office work and how to pursue functional text input as part of the bigger vision. Finally, we illustrate how the latest MR developments can enable employees to work from home but sit virtually in their familiar working environment or attend business meetings far away. We believe that emerging MR technology can overcome some of the telecommuting limitations and foster improved, nomadic working environments that do not require a centralized physical workspace.

NOMADIC WORKPLACE

The vision of shared telecooperation between distant individuals and spatially augmenting the office space[19] to enhance the working environment is not novel. However, the current (SARS-CoV-2) pandemic fundamentally changes the initial parameter since employees are required to work from home. Furthermore, today's head-mounted displays (HMDs) are capable of presenting rich virtual environments while blocking external visual or auditory distractions. MR enhanced offices yield several advantages, including complete control of the virtual office space while overcoming physical limitations, enhanced privacy, and location flexibility.[9] We define nomadic offices as a personalized virtual office setup that superimposes physically existing office environments into augmented or virtual reality (VR). Nomadic offices overcome the boundaries of personal presence and physical burden carrying setups to utilize them. The implied ubiquity of personalized nomadic offices will support users to work within familiar environments. Hence, we envision nomadic offices to increase the perceived naturalness and efficiency of office work in the long term when the interaction with virtual office environments has moved into the research focus.

A fundamental requirement is the effortless interaction with the computer interface to enable employees to work as efficiently in a virtual environment as in a real office. This includes, in particular, text input and manipulations. To enable virtually immersed employees to do fast generic text manipulations, they need to localize and reach out for a physical keyboard and understand the keyboard's location in relation to their own fingers.[12] Previous research presented several solutions for text input while being immersed in virtual environments.

McGill *et al.*[16] attached a webcam to an HMD to blend the keyboard and hands of the user within VR to examine the ability to input text within a virtual environment. This approach only provides monocular depth cues that affect orientation. In contrast, Grubert *et al.*[10] synthesized the entire environment and presented the user's hands as semitransparent spheres. A stationary tracking system provided the necessary location data. Similarly, we build a stationary setup.[12] Despite that, we tracked and presented a detailed representation of a full interactive synthesized hand. With all these implementations, employees can facilitate almost the same text input speed they achieve in the physical world. Unfortunately, the proposed solutions and apparatuses are stationary, expensive, or require calibration (see Figure 1). Hence, they are, at the moment, not ready for mainstream use. With fewer requirements, an easy-to-use and portable solution, people could be empowered to work and meeting in VR.

We recently presented the first steps in this direction, with a low-fidelity apparatus that allows for untangled and calibration-free text manipulation on a physical keyboard while being immersed in VR. This development offers similar performance while keeping the system requirements low. The apparatus comprises only an off-the-shelf smartphone, VR viewer, and a wireless keyboard; hence, it is fully portable and can be used by a broad audience. We are using optical maker tracking (see Figure 2) to identify the keyboard and user's hands that are dynamically blended into the VR, allowing fast text input and manipulation.[11]

FIGURE 1. Left: A virtual office workspace resembling a physical one. Right: Stationary apparatus comprising a workstation, MR headset, and an accurate optical hand tracking system to enable text input in MR.

FIGURE 2. Left: Virtual office that is operated by a user outside of a physical office environment. Right: Lightweight, mobile setup comprising a smartphone, MR viewer, and physical keyboard to enable text input in MR.

Having the ability of general text manipulations, such as composing an email while being immersed in VR offers many new opportunities for the future of work. Since there are no technological or physical limitations for the screen arrangement or design, novel VR offices allow for the creation of entirely new environments with vast 3-D display space in any direction. Furthermore, user interfaces are no longer bound to rectangular 2-D displays limited by our desks' size. Future VR offices could supersede current interaction paradigms and enable improved work performance.

We are confident that VR has the potential to change the way we work. We envision a shift toward nomadic office workers that can work productively in safe physical isolation, but immersive HMDs compensate for physical limitations, loneliness, or the lack of social interaction. Moreover, the virtual nomadic office that may visually resemble their physical counterpart strengthens the boundary between work and home that is currently dissolving.

HOW OFFICE WORKERS TOIL

Knowledge workers develop new products and services by applying their theoretical and analytical knowledge. Their high level of productivity and creativity is based on the ability to solve very complex and diverse sets of real-world tasks and problems. These professionals are comprised in many domains; hence, their individual type of work and work style can broadly differ. However, central aspects include communication skills and accessing or applying new information. In a nutshell, these tasks can be broken down into creating, editing, or reading documents and media. Further tasks cover collaborative decision-making processes along with sync and asynchronous communication. If these tasks are further divided into computer-supported microtasks, knowledge work mostly involves reading and writing or content creation and modification coupled with continuous communication.

Having access to a typical desktop computing system in a known physical office environment helps workers perform any of these tasks with ease. Multitasking, multiple windows, and sufficient display space can enhance creativity, and overall performance.[15] With very little lead time, SARS-CoV-2 forced employees to resemble their specific working setup in a domestic environment. Given the potential restricted physical space and further limitations, building an efficient working environment can be cumbersome. Hence, the fallback to a reduced setup, e.g., laptop or smartphone, is obvious. Unfortunately, these minimalist systems make the tasks mentioned above more laborious since the benefits of multitasking and large display real estate are decrease. Creating new content while consulting an additional document or media requires multiple simultaneous interactive applications. Either the visualization is shrunk in size to fit the available screen space or can only be consulted subsequently. On many smartphones, interacting with two applications is still not supported. In consequence, switching between applications is necessary, hindering an uncomplicated workflow.

Future MR systems offer the chance to overcome these limitations and create a multiscreen environment within the headset. Thus, the worker can experience a fully fleshed-out computing environment that supports any task in the most eloquent way. As a prerequisite, certain aspects need to be considered to make MR systems a productive work environment rather than a distracting tool.

CREATE AND EDIT CONTENT

Modern computing systems and advanced applications enable us to create and edit any medium effortlessly. For stationary systems, a physical keyboard and mouse are still the essential input methods for high-bandwidth general-purpose interactions.[16] Typewriting is the predominant method for generic text input for desktop computing. To enable knowledge workers to work as efficiently in a virtual nomadic office as in a real office, they require the same high-performance input devices. Efficient text input, while being immersed in an MR environment, is the most critical but not yet entirely solved challenge. Alternative input modalities such as gestures or speech are potential alternatives but are not yet effective or suitable for generic input or in public spaces. Furthermore, editing and browsing documents using these methods is rather slow, inconvenient, and can cause fatigue. Consequently, smooth mouse and keyboard interaction as a primary input method in an MR nomadic office is required.

EXPLORE AND EXAMINE CONTENT

Scrolling through large documents or datasets, searching for specific information, can be a tedious task. Using large high-resolution displays can help users while examining the content or use multiple applications simultaneously. For that reason, many professional workspaces are equipped with multiple displays. However, limited space and resources often constrain the available display space in a home or nomadic office. Hence, exploring and examining media and documents simultaneous is more demanding.[15] An augmented nomadic office provides the chance to create multivirtual screens within the environment. Thus, allowing the user to interact with several applications side by side. Given a future high-resolution headset with a wide field of view, extended display real estate is available.

REALIZING THE AUGMENTED NOMADIC OFFICE

Enhancing the nomadic or home office environment can be done by either improving the input or output capabilities of the facilitated computing system. Specifically, the users' ability to create and edit or explore and examine content is of great importance.

Using a virtual or MR HMD allows creating any number of personal displays at user-centered locations. However, it may interfere with the direct visual perception of the known peripherals, namely the keyboard and mouse. In order to interact with the computing system and edit or create documents, it is a fundamental requirement to realize effortless typing within the MR environment. We proposed to continue to use the physical keyboard in MR environments and recently build multiple prototypes that support the user to localize and reach out for the keyboard and understand the keyboard's location in relation to their own hands. Thus, being able to enter and manipulate documents on the physical keyboard while being visually immersed in a virtual environment.[11,12] Our stationary implementation of a virtual office comprises an HMD, a workstation, and an accurate motion tracking system for finger and keyboard tracking. Retroreflective markers affixed to each hand ensure precise tracking of each hand, which is represented within the MR environment (cf. Figure 1).

With the depicted prototype, experienced typists reach almost outside-MR typing performance while visually perceiving a virtual office space. Furthermore, less experienced typists typed just 5.6 words per minute slower compared to a traditional desktop setup. Based on the use-study, we concluded that optimizing the visualization of hands in MR is essential, especially for inexperienced typists, to enable a high typing performance.[12]

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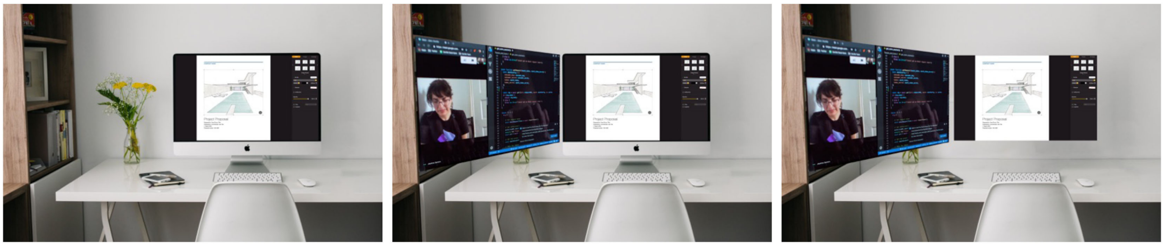

FIGURE 3. Left: Regular home office working environment with only one display. Center: Augmented workspace with virtual displays extending the available screen space. Right: Portable nomadic office with entirely virtual display space presented through HMD. Only the peripherals remain physical for familiar interaction.

In contrast to the stationary prototype, our portable implementation comprises only a modern smartphone as the main component. The smartphone is incorporated with an MR viewer to create a simple self-contained HMD. The latest smartphone generation implements advanced sensor fusion algorithms to enable sufficient six degrees of freedom tracking and environment tracking. Thus, allow the rendering of compelling MR environments. For our portable MR offices, a wireless keyboard is paired with the smartphone and used for text input. The keyboard is visually tracking, and a registered live video feed of the keyboard and users' hands are rendered within the MR environment (cf. Figure 2).

In a user study, we compared the portable MR office's performance with a regular smartphone in terms of creating or copy-editing documents. The results showed that participants have significantly higher input speeds when being immersed in MR compared to smartphone input, while error rates remain low. Although copy editing required more time to complete in MR, participants enjoyed interacting with the large virtual displays.[11]

With today's off-the-shelf hardware components, the prototype's portability comes at the cost of render quality and tracking accuracy. From both studies, we can conclude that the stationary solution offers fast text input and a reliable virtual office for experienced office workers or typists, while novice typists still require advanced guidance. The smartphone-driven virtual nomadic office offers ample display space and a first glimpse toward future products and services. Yet, interaction is not continuous enough for productive uninterrupted office work.

Besides the ability to create and manipulate text, it is also essential that the visualization of the text or media is designed that the worker can comfortably consume it. Today, the resolution of facilitated HMD has a significant impact on the user experience and readability. Dingler *et al.* investigated parameters such as text size, font, and background as well as convergence, view box dimension, and positioning of text on the reading experience. Based on their user study they conclude that the device-specific fixed focus predominantly affects the comfortable reading distances and should be considered during the design of MR environments.[3] In a more recent study, Wei *et al.* examined the influences of different 3-D shapes on the reading performance of text renderings. Their results suggest that text warping should be limited to the horizontal axis within certain bounds.[20]

Overall, only if the input and output modalities meet or surpass the rigorous requirements of real-world potential for content creation, manipulation, and examination, the employee can spend extended periods within an MR nomadic office and appreciate their enhanced office.

FUTURE OFFICE

Nomadic offices change how we will work in the future. Workers can directly utilize the spatial resources, social interactions, and available screen space within telecommuting scenarios using nomadic offices that are ubiquitously available. We propose the following scenarios for working in MR offices based on our expertise through the developed prototypes, conducted user studies, and literature reviews.

AUGMENTING THE PHYSICAL OFFICE

When the physical space in an office is limited, it can still be extended by virtual elements to create a nomadic office scenario. While physical office components provide a better sensation of haptics,[12] virtual elements can extend the amount of information that can be displayed. Figure 3 illustrates how such virtual elements can be utilized to extend the physical screen space. Previous work showed that the extension of

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screen space could result in a higher efficiency.[1] Here, we envision that screen space can be spatially extended in nomadic office environments, hence providing the user with as much screen space as required at any time (see Figure 3, center). In a very recent study, Pavanatto *et al.* prototyped such a hybrid office environment with physical and virtual screens and investigated the effects of screen virtualization on performance and comfort. They conclude that for performing serious productivity work, virtual displays still provide poor usability and reduced performance.[18] In particular, for long working sessions, current MR technology cannot cope with physical monitors in terms of visual fidelity and ergonomics, yet next generation MR HMD[a] will most likely meet these requirements.

MOBILE OFFICE

Following this stream of virtualization, we envision the next version of nomadic offices to be highly dynamic, with visual elements being entirely virtual. The visual representation of the whole office environment, using virtual elements only, is represented through an MR HMD (see Figure 3, right). This shift to the virtual environment allows us to instantaneously materialize a stationary working environment with minimal requirements to the physical situation. Moreover, the HMD and active noise-canceling headphones could fade out external distractions selectively. Nonetheless, research is being conducted on alternative text input modalities that could replace the physical keyboard in the future mobile virtual offices,[6] we currently suspect that the prevalent input methods, such as mouse and keyboard, will remain physical.

OPEN RESEARCH CHALLENGES

The global pandemic forced us to rethink the necessity of centralized workspaces. The widespread availability of nomadic offices will change how and where we work in the future. Offices will be available "on-the-go" regardless of our location and environmental context. The concepts mentioned above promise positive benefits. However, several challenges remain to be investigated in future research.

COLLABORATION WITH USERS

Inviting other users into their own virtual spaces remains an interesting research question. Entering a distant nomadic office of other users blends virtual and actual office environments even more: users can stop by if they seek help, intend to collaborate, or want to work in a social setting. Moreover, social office settings are known to prevent adverse psychological effects,[7] increasing the environmental work quality. However, creating a virtual office environment and enabling seamless social interaction is still a challenging research area. This includes modalities to interact with peers, visualize avatars, location-independent coworking spaces (e.g., collaborative whiteboards), input techniques, and proxemic voice transmission.

Research and industry suggested multiple promising solutions such as the FIESTA system,[14] Mozilla Hubs,[b] or Spatial.io[c] to collaborate in MR. The recent presentation of Microsoft Mesh[d] also indicates pronounced potential of realizing collaborative virtual nomadic office environments. Yet, these systems are not mainstream nor widespread due to the basic implementation of collaboration, heterogeneous technology availability, and capabilities, as well as cross-platform incompatibility.[4] For example, Mozilla Hubs provides a reliable platform to meet, work, and collaborate in MR. However, previous research proposed focusing on the usability of collaborative systems, increasing their ease of use and proliferating them into a utile interactive system for everyday use.[5]

INCLUSION OF THE ENVIRONMENT

Utilizing the user's concurrent physical environment in a virtual office environment is currently underestimated by HCI research. Virtual office spaces can adapt to the user's physical environment to provide haptic proxies (e.g., for interaction with whiteboard) and a suitable 3-D representation of the environment while the user at home on-the-go, or traveling. The immersion of virtual environments benefits directly from the sensed surroundings from the user.

INTERACTING IN NOMADIC OFFICES

Interaction in MR is an intensively researched topic. Most of the research around input in MR has focused on input using controllers or keyboards. However, input in nomadic offices goes beyond controller-based input requiring sophisticated text input and operation through pointing. While previous research looked into how text input can be provided in MR, they are affected by drawbacks, such as the need for a physical keyboard. Furthermore, additional sensor data,

[a] [Online]. Available: https://varjo.com/products/xr-3/

[b] [Online] Available: https://hubs.mozilla.com
[c] [Online] Available: https://spatial.io
[d] [Online] Available: https://www.microsoft.com/en-us/mesh

including gaze, head or hand orientation, along with spatial information of the environment, are available. Consequently, large ergonomic virtual environments[17] or new enhanced interaction paradigms can be envisioned. Here, past research investigated several virtual display setups and their placements (i.e., angle of the display placement relative to the user's head), finding differences in interaction comfort for different configurations. The ergonomic design of virtual displays is an emerging research topic with the ubiquitous availability of smart glasses.

Future research should investigate how these new sensors and input methods can be designed and implemented to support natural interaction.

CONCLUSION

The present pandemic requires drastic measures to curb. Consequently, many workforces operate from home, which manifests in old and new challenges for all involved individuals. This article presented emerging challenges and introduced MR workplaces as nomadic offices to foster a productive and meaningful working environment. We highlight the potential of MR workspaces, including the freedom to develop the virtual office according to the employees' needs or resemble the original office to stick to a known environment and keep the boundary between work and home. For the design of future nomadic offices that are experienced in MR, several challenges remain, including the effortless input and output in such offices. In a substantially globalized world, we envision a virtual nomadic office as a practical and consistent environment at work, at home, or while en route.

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