A concept for a novel hybrid augmented reality computer workstation for virtual product development

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Abstract

Extended reality user interfaces for engineering design often suffer from gaps in the user's workflow. Usually, the user must at least put on hardware, but often also data preparation is needed. This research aims to close these gaps by proposing a setup fusing desktop and immersive user experience into a hybrid augmented reality computer workstation. Here the user can decide for each operation what modality is best suited, using the strengths of both interfaces while avoiding their drawbacks. In this paper, a concept for such a hybrid computer workstation is developed using the morphological matrix method. Different solutions for the main features, holographic stereo display, spatial interaction, and the software architecture, are discussed and a reasoned combination is proposed as a feasible concept.

Keywords

CAD, Augmented Reality, Product Design, Morphological Matrix, Computer workstation

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1. Introduction

Plenty of opportunities for both virtual reality (VR) and augmented reality (AR) in the design process have been identified and explored in research [1–4]. Especially the transformation of computer-aided design (CAD) tasks from a screen to immersive systems has seen a lot of attention, starting in the late 1990s [5]. In existing research, the immersive systems replace the CAD tool either completely or in specific tasks and while many approaches are successful for their specific use-case, XR applications cannot fulfill all the enormous capabilities of modern CAD-suites. It seems inevitable that a successful, productive XR support for product design has to work in symbiosis with the established tools and interactions techniques.

Most XR applications for engineering design, especially virtual reality (VR) focused ones, suffer from gaps in the user's workflow. On one hand, there is a data-gap: Generally, XR applications work with optimized mesh geometry which firstly has to be generated from the CAD-data. If the data is modified, it is a non-trivial task to apply the changes back to the CAD files, but there are approaches to tackle this problem [6]. On the other hand, there is a hardware-gap: Most modern immersive devices rely on head-mounted displays and often hand-held controllers. Therefore, to change from classical to immersive workflows, at least a headset must be put on. More often, a specific room or area must be visited.

This research aims to close these gaps in current immersive extensions of the product designer's workflow by proposing a setup fusing desktop and immersive user experience (UX) into a hybrid augmented reality computer workstation for virtual product development. Here, hybrid workflows allow the user to decide for each operation what modality is best suited, using the strengths of both classic and immersive interfaces while avoiding their drawbacks. Our vision of this hybrid workstation, showing its main components, is shown in Figure 1.

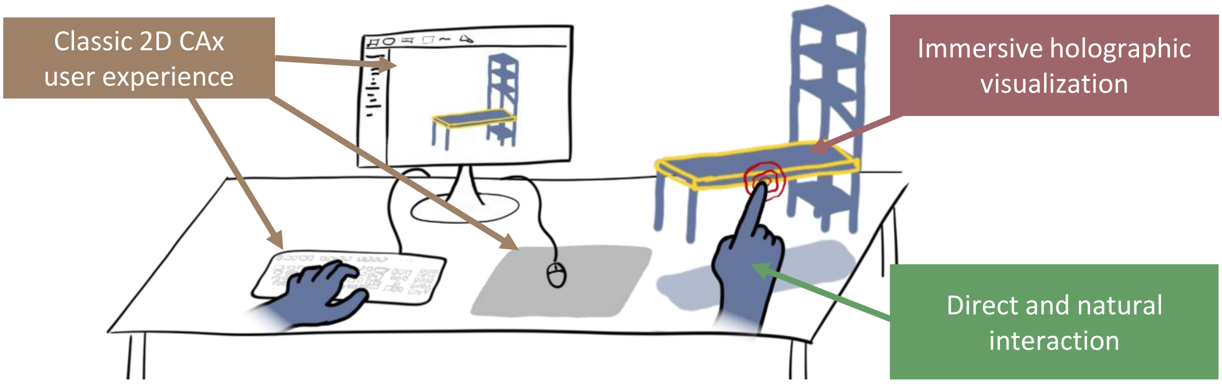


Figure 1 Our vision of a hybrid augmented reality computer workstation for virtual product development

At first, we present a brief overview of the related research in chapter 2. Afterwards the research questions and our methodology are stated. In the main chapter 4, the main requirements are found, the main features derived, and the morphological matrix method used to explore the solutions space systematically. The resulting concept and potential use cases are described in chapter 5 before the articles closes with a conclusion.

2. Related Research

Using extended reality (XR), in particular AR, in product development is an active research field for many years. 2012, Nee at al. summarized AR applications in design and manufacturing with many of their examples dating back till the 1990s [1]. Already at that time, they found many design applications from *Contruct3D*, providing basic modelling for geometry education to *ARCADE* allowing users to generate CAD models combining virtual and real objects [7], [8]. More recent surveys focused on co-design in manufacturing [9], the usage of the Microsoft

HoloLens [3], and a classification of industrial AR applications [10] provide a comprehensive collection of the relevant research activities.

While there is a lot of research done using AR in product development in general, not much can be found towards hybrid AR computer workstations extending classic desktop user experience with immersive components. Most relevant are earlier works at our institute, where intuitive virtual reality modeling systems were proposed [11], [12]. This work includes discussions about hybrid workplaces and concludes with the presentation of a hybrid system consisting of a VR head-mounted display (VR-HMD) and a classic desktop setup. Changing between immersive and monitor-based workflows is easy, as both modalities use the same CAD-session. But of course, the closed-off glasses have to be put on and off in between. See-through AR-HMDs were dismissed for their inferior head tracking and field of view. Modern devices have made significant improvements in these areas. A similar system, but using such an AR-HMD, was shown by Millette at al. and is called *Dual CAD*. Here a simple CAD software was developed with two separate user interfaces. A classic WIMP (Windows, Icons, Menus, Pointer) interface and an AR variant. Only a button press in the desktop program is necessary to switch between the two modalities. For increased tracking precision and more in- and output possibilities this system additionally utilizes a smartphone in the user's non-dominant hand. Using this, novel interaction techniques for creating prismatic objects and drawing on object surfaces are implemented. We argue that both systems from Fechter et al. and Millette el al. are still sequential in their usage and not truly hybrid. While they are combining immersive and classic UX, there is still a back and forth instead of a concurrent workflow. With the concept proposed in this paper, we want to achieve the latter.

A demonstration much closer to our vision was shown at Microsoft's Worldwide Partners Conference in 2015 in the wake of the release of the HoloLens 1. Microsoft and Autodesk had partnered showing *Maya* running on a Desktop PC and the HoloLens 1 in a hybrid manner [13]. It showed a motorcycle design in the desktop Maya application with a hologram of the model viewable through the HoloLens. Only simple user interactions were shown, possibly caused by the limited input options of the first HoloLens iteration. Furthermore, there is no official documentation about this demo left to reference and no software was ever available suggesting it was never in a fully usable condition.

3. Research questions and methodology

In our research we want to develop and evaluate hybrid AR workflows for virtual product development. This specific contribution's target is to design a hard- and software concept for a hybrid computer workstation which would allow us to work on the larger goals. For an unbiased and thorough concept design process, we apply the morphological matrix method [14]. Aligning with this method, this paper aims to answer three research questions.

- **Q1 –** What are the essential features a hybrid AR computer workstation must provide?
- **Q2** – Which technical solutions are available to realize those features?
- **Q3** – What combination of these solutions puts together the most promising conceptual set-up to achieve productive hybrid workflows for virtual product designers?

At first, the main requirements for the novel workstation are collected. From those, the critical features are derived, answering **Q1**. For each feature, potential solutions are researched and discussed, answering **Q2**. The last question, **Q3**, is the most intricate to answer. The solutions by themselves and their compatibilities with each other have to be considered. To do so, existing studies and personal experiences are consulted.

4. Morphological analysis

The three main requirements for the hybrid augmented reality computer workstation can be derived from our vision, shown in Figure 1:

- **R1 – Holographic visualization:** A stereoscopic display of the currently worked on model, which is placed comfortably in the users reach. It needs to be continuously synchronized with the authoring tool in use and rendered at real-time speeds for intractability.
- **R2 – Direct spatial interactions:** For a rich interaction with the hologram, spatial, natural, and stable interactions supported by precise feedback are necessary.
- **R3 – Unobstructed usage of the classic user experience:** The classic peripherals consisting of monitor, mouse, keyboard, and potentially a 3D mouse have to be usable without impediment.

From these requirements, the main features of the hybrid AR computer workstation are found. To fulfil **R1**, a stereographic and holographic display technology is needed and similarly, for **R2** a spatial interaction technology has to be found. Both choices will have to make sure **R3** stays satisfied by not disrupting the user in interacting with the familiar desktop interface. A software architecture coupling the immersive visualization and interaction with a classic desktop virtual product development tool, typically a CAD software, is necessary as a third feature. This ensures **R3** and has to support the chosen solutions for the other two features. These three features form the first column of the morphological matrix, shown in Table 1, with the cells to the right of them showing the corresponding potential technical solutions which are described in more detail in the upcoming sections.

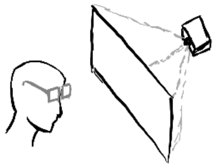
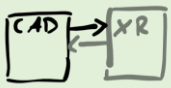
4.1. Holographic stereo display

The biggest impact on the whole setup has the chosen holographic display technology determining the possible placements for the three-dimensional content, the image quality both in resolution and opacity and necessary wearables.

Optical see-through head-mounted-displays (HMD), such as the HoloLens and Magic Leap are a promising option, as they combine many benefits: Their head-mounted design and therefore a dynamic viewing frustum, allow the placement of 3D holograms everywhere in the real world. Furthermore, they usually include many useful sensors built in. In case of the HoloLens 2 [15], a collection of cameras and inertial measurement units (IMU) provide head, eye, and hand tracking. The device also creates an approximate mesh reconstruction of the surroundings. With the *Mixed Reality Toolkit (MRTK)*, Microsoft provides a powerful SDK to build applications making use of all this data [16]. Drawbacks of the current see-through devices are the relatively small fields of view and transparent renderings. Both available consumer products are standalone devices, providing their own power and processing to allow mobile deployment. This is usually an advantage, but for this application it adds complexity as a high-performance workstation is always present. For the hybrid workflows, the immersive visualization data and user input have to be exchanged between the PC and the HMD. A see-through HMD tethered to a PC, similar to fully immersive VR-HMDs, would be ideal. Older devices like that, e.g., the *Meta 1* exist, but none with up-to-date technology and good software support is known to the authors.

The second option are video-see through HMDs, such as the Varjo XR-3 and HTC Vive Pro 2. Here the user does not see the real environment directly but captured by cameras and shown on the HMD's display. This allows for a greater FOV and fully opaque virtual content. Furthermore, the mentioned devices are tethered to a PC, allowing a simpler system architecture. While these are preferable properties, the indirect perception of reality compromises the classic desktop interactions and is therefore inacceptable for long periods of hybrid working.

Table 1 Morphological matrix for the design of a hybrid AR computer workspace for virtual product development. First column shows the necessary features, all other columns contain potential technical solutions for them, exemplary devices and references to relevant research using the technology. The solutions highlighted in green are selected for the proposed concept (Section 5).

Features	**Potential technical solutions**			
Holographic stereo display	Optical see-through glasses *Magic Leap, Microsoft HoloLens* [3], [7], [8], [17–20] 	Video see-through glasses *Varjo, Vive Pro* [20], [21] 	3D Monitor *Schneider Digital, NVidia 3D Vision* [22] 	Projection-based systems *Powerwall, Cave* [5], [6], [23], [24] 
Spatial interaction	Data Gloves *HaptX* [5], [20], [25–27] 	Hand-held Controllers *Vive, Flystick* [6], [8], [18], [24], [28] 	Desk-mounted haptic device *Haption* [29] 	Optical (hand) tracking *Leap Motion, Kinect, AR Glasses* [7], [12], [17], [19], [23], [30–32] Ultrasonic feedback *Ultraleap Stratos, Emerge Wave 1* [33] 
Software architecture	Integrate XR into CAD [5] 	Custom XR Application - Without CAD Kernel: [7], [18], [19], [23] - With CAD Kernel: [6], [12], [17], [24], [26], [34], [32] 	Concurrent CAD & XR Application [28], [30] 	

A third option could be the usage of a 3D Monitor. These are desktop monitors which support either active or passive stereoscopic display. The active verity, using a high refresh rate and a shutter glasses (e.g. NVIDIA 3D Vision), were very popular for a short time mostly for entertainment (TV and gaming) but are barely present in the consumer market today. Passive displays, using much simpler and lighter, polarized glasses are rare, but exist for professional use [22]. Independent of the technology, they provide excellent image quality and could additionally work as a conventional monitor for non-spatial tasks. For the proposed use-case however, they have too many drawbacks. The hologram can only be placed in a very specific area, not all variants provide head tracking, and there is little software support.

The last option that is discussed here, are projection-based stereo systems such as power walls or caves. These systems work similar to passive 3D monitors, by splitting the images per eye through polarization. For a hybrid workstation, a desk could be placed in front of this display system as proposed by Fechter at al. [11]. This technology could provide flexible hologram usage while only needing lightweight polarized glasses. But the projection systems price, size and complexity make this solution hard to scale.

4.2. Spatial interaction

To allow hybrid workflows with the holographic content, the ability for spatial interaction is essential. While spatial input and spatial feedback are usually fulfilled by different technologies, they are strongly connected and often provided within one device.

The most widespread spatial interaction are handheld controllers. These are devices where position and rotation are tracked in space. They are held in the user's hand providing buttons and triggers. *Flysticks*, tracked by expensive infrared systems are in use for a long time. With the advent of cheaper, customer-grade HMDs (*Oculus Rift, HTC Vive, Valve Index)*, new tracking solutions were found making use of IMUs. The physical buttons make precise and confident input possible and vibration motors add haptic feedback beyond the buttons. This technology is state of the art for PC-based VR systems, but for the proposed application, the hands need to be free. Another special kind of handheld input is the haptic device. These arm-like mechanisms can be placed on a desk and be used for very precise input and force feedback. As this can be held in place, this might allow a smoother transition.

Another interaction device, popular in the early days of VR research is the data glove. These gloves come with sensors determining your hands' and fingers' positions and allow for both haptic and force feedback. They have come a long way, but are still too intrusive for the proposed hybrid interactions. [27]

An upcoming and promising technology is optical hand and finger tracking [35]. Reasonably precise optical hand pose estimation for consumers started with the introduction of the *Leap Motion Controller* in 2014, but only picked up bigger interest when the technology got applied to VR. Recently many XR devices, included hand tracking as a built-in input option, e.g. *HoloLens 2, Meta Quest 1 & 2* and *Magic Leap*. This technology allows the implementation of natural interaction schemes mimicking how we operate in the real world. This technology is the only option that offers direct interactions with the hologram, without any additional devices or markers and therefore brings no interruption to the classic workflow. There are even recent developments using ultrasonic speaker arrays to project vibrations onto fingers mid-air which could be applied for haptic feedback [33].

4.3. Software Architecture

With the hardware components discussed, there is one other aspect of the system that has to be explored: How to build the software connecting spatial visualization including interaction with a full feature CAD authoring tool. Both Berta et. al. [5] and Fechter et. al. [11] have similar discussions of different architectures in their articles.

With deep enough access to the source code, the necessary libraries for the immersive rendering and interactions can be integrated into the CAD application itself. One of the first publications regarding the integration of VR and CAD from 1999 goes this route, including the *Fakespace* capabilities into *Catia* [5]. This would also most likely be the option the software vendors themselves would choose if they implemented something like this as they obviously can access their code wherever they want, even reusing their rendering. For our prototype this is not an option, as no commercial CAD tool we know of allows enough access to realize this.

The opposite approach is to build a custom application. Today a game engine would be a good starting point as we discussed in an earlier paper [32]. Prior to their advent researchers used other VR frameworks such as *VR Juggler* or *OpenSceneGraph*. A CAD-Kernel can be included to supply the modeling capabilities as shown by Bourdot et. al. building their VR-CAD integration with the *Distributed rendering system* and internally using *OpenCASCADE* [24]. Also commercial CAD tools can be run windowless (headless) from another application and used as the modeling and persistence back-end [32]. With simpler use-cases the geometric operations can also be implemented from scratch as done by Valentini for example [19]. For the proposed hybrid workflow, the classic WIMP interface is necessary alongside the immersive one and would have to be custom build in this software design as well.

The final option is to have the two applications running concurrently, communicating with one another. Exemplary researchers going this route are Fechter et. al. connecting a custom VR assembly modeling interface to *ANSYS SpaceClaim* using its API [30] and Feeman et. al. using text-based network communication between *Autodesk Stingray* and *Autodesk Inventor* [28]. While this architecture is the most complex, it allows both sides to run on their own and process their in- and output independently.

5. Proposed concept

In this section our proposed concept for a hybrid augmented reality computer workstation for virtual product development is presented. For this, the choices for each sub-system are explained and how the elements are interconnected. Figure 2 shows the main components and their interactions. It is using see-through glasses, specifically the *HoloLens 2*, to display the holograms and its marker-less optical hand tracking for direct interactions. It is based on a bi-directional software framework combining *Siemens NX* as the CAD modeling tool and the *Unreal Engine*, running concurrently.

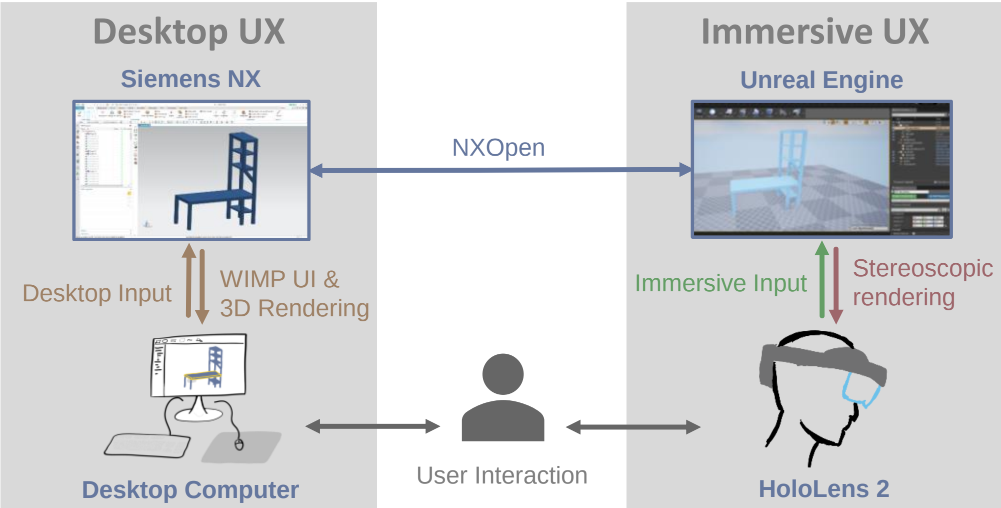


Figure 2 Overview of proposed system components and their interactions

Optical see-through glasses are chosen as a display technology for their flexible hologram placement and multeity of sensors. While the see-through screens themselves have a slight negative impact on the visual perception of the desktop UX, we don't think it is enough to be unpleasant. As the specific model, we have chosen Microsoft's *HoloLens 2*. Other available AR-glasses, most prominently the *Magic Leap* provide similar features and could be used as well. From our standpoint, Microsoft's option is the most mature AR device on the market which not only ensures many troubleshooting resources but also makes it the most probable for professional adoption. It has built-in optical hand tracking, which is used to perform the direct interaction with the holograms. This makes changing from desktop to immersive workflows frictionless as no controllers or markers are necessary. The increased complexity from the device being standalone can be tackled by utilizing holographic remoting [36], this allows the device to be used almost as a tethered PC-powered device. Instead of having to build and deploy the holographic application on the device, it can be run on the same PC with the CAD and both the rendering, and the sensor data are transferred automatically between the two over a network connection. With this, the communication between the CAD and immersive application, in turn, does not need to be network based and the API libraries for the CAD do not have to be buildable on the *HoloLens* Platform. Additionally, this leverages the graphics performance of the workstation PC, allowing the display of far more complex model than the *HoloLens 2* could handle on its own. Running concurrently to the CAD tool, the holographic application is developed using the *Unreal Engine*. Game engines are perfectly equipped for 3D rendering and spatial interaction development [32]. Both *Unity3D* and *Unreal Engine* have all necessary capabilities. Our choice is to leverage previous experiences and code. For similar reasons, our CAD tool of choice is *Siemens NX.* It has a powerful scripting API, *NXOpen*, which can be used directly from the game engines *c++* code to implement the bi-directional connection. This should allow to include holographic interactions deep into the classic desktop workflow.

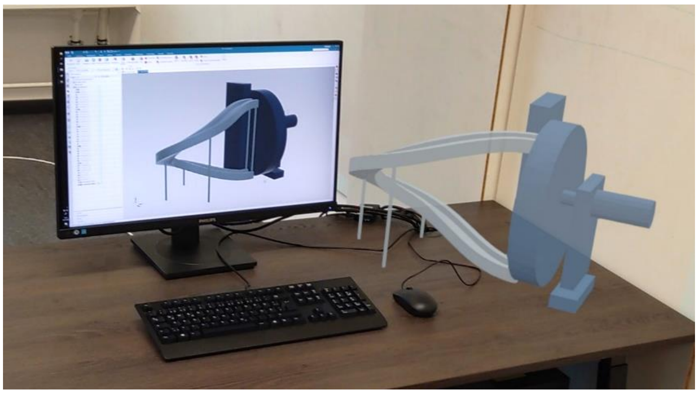


Figure 3 Augmented reality photo showing a mock-up of the hybrid AR computer workstation. An exported triangulation of the CAD model is shown on the HoloLens 2 using the built-in application *3D Viewer*.

Figure 3 shows an augmented photograph taken with a HoloLens 2 of what the user sees using the hybrid AR computer workstation. There are plenty of use-cases imaginable for this technology within the workflow of virtual product designers. For most of them, there is already scientific research with purely immersive interfaces which can be transferred to the hybrid workstation. The immediate intuitive inspection of the current work model as a 3D rendering is a rather simple benefit, but it can help making quicker and better decisions while modeling and in design reviews [37]. An actual hybrid interaction would be the selection of elements within the classic workflow [38]. For example, the user might want to create chamfers: He selects the corresponding operation within the desktop interface, then lifts the hand and selects the desired edges by tapping them in the hologram and finally commits the operation again in the classic UI. The creation and modification of parametric curves and surfaces is notoriously ill suited for a two-dimensional interface by its inherent three-dimensional nature. An immersive alternative would allow for natural manipulation of the control points [31] or even the elements themselves [20]. For a more creative workload, the hologram can be used for three-dimensional sketching and ideation with simple mid-air line drawings [39] or by creating basic geometric shapes [40]. Those tools should be beneficial for annotation in design reviews as well. One last use-case we want to discuss here is the assembly modeling. A natural grabbing algorithm can be applied to move sub-assemblies around and combine them. With clever algorithms it is possible to detect the necessary constraints automatically and if these assignments are wrong, a correction using the classic interface is easily done [30], [41].

6. Conclusion

This is a first work towards designing a hybrid AR computer workstation for virtual product development, arguing the necessary components and their combinations answering our three research questions. From here, developing a working prototype, on which the predicted benefits and use-cases are evaluated in user studies, is the next logical task.

We believe this new workflow has the potential to be integrated as smoothly into the user's workflow as touch screens on laptops have been in the last couple of years: Regular users intuitively deciding when they can achieve their goal quickly using their hands on the screen and when to use the trackpad. Similarly, the hybrid augmented reality aims to be a spatial extension to existing modalities, providing easy to use and satisfying interactions without breaking existing ones.

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