# USE CASES FOR A HYBRID AUGMENTED REALITY COMPUTER WORKSTATION IN CAD WORKFLOWS

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## ABSTRACT

Many immersive approaches for design activities show a great potential for their specific use cases, but still overall usage of extended reality technology in product developers day-to-day work is little. The user's workflow between classical desktop work environment and its immersive counterpart is interrupted by both a data gap and an interface gap. The three-dimensional product data usually needs preparation and the user has to physically change the interface in use. The hybrid augmented reality computer workstation aims to close these gaps. A hologram of the current model is visualized next to the screen in reach of the user for intuitive inspection and spatial interactions. In this paper we present use cases for this novel immersive workstation in the CAD workflow. An explorative user study of the typical product designer`s workflow reveals the most common activities. Guided by those, eight uses cases are formulated and classified into fundamental, drafting, and modelling CAD tasks. These cases include novel hybrid augmented reality interactions derived from literature, which are assessed with respect to their applicability.

**Keywords**: Computer Aided Design (CAD), Virtual reality, Workspaces for design, Augmeted Reality, Natural User Interfaces

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# 1 INTRODUCTION

Extended reality (XR) interfaces supporting the design process have been an active research topic for many years. From there, immersive presentation and inspection of spatial data has been adopted in the industry. Whether it is virtual reality (VR) visualization in design reviews and ergonomic studies or augmented reality (AR) instructions for manufacturing steps. In contrast, applications using the spatial in- and output for effective creation and modification of the three-dimensional product data are mostly done in academia. Multiple examples for the transfer of different computer aided design (CAD) tasks into virtual environments are mentioned by Coburn et al. (2017). Even though many approaches showed a lot of benefits for their use case, overall industrial usage of immersive CAD is little. Reasons for this are gaps between an engineer's day to day work environment and the immersive counterpart. First, there is a data-gap: Generally, XR applications work with optimized mesh geometry which has to be generated from the CAD data. While the tessellation of the parametrized model is done automatically, getting a mesh that performs well on even low powered devices often needs manual processing. If the data is modified in the virtual environment, it is a non-trivial task to transfer the changes back to the CAD files. However, there are approaches to close this data gap, like a tight coupling between a CAD kernel and a VR application (Bourdot et al., 2010). Secondly, there is a gap between the user interfaces: Most modern immersive devices rely on head-mounted displays and often hand-held controllers. Therefore, the change from classical to immersive workflows requires to put on at least a headset and picking up controllers. More often, a specific room or area must be visited. While these gaps aren't necessarily huge, their existence makes frequent changes between the interfaces not viable for small tasks.

The proposed hybrid AR computer workstation aims to close these gaps with modern augmented reality technology (Harlan et al., 2022). A hologram of the current model is visualized next to the screen in arms reach of the user. This hologram extents the conventional desktop interface with immediate three-dimensional visualisation and direct spatial interactions. This additional spatial modality allows the user to work in the same dimensionality as the data, reducing the required mental load. Such hybrid workflows would be applicable to all activities using 3D data, from architecture to entertainment. This work focuses on virtual product development (VPD), specifically computer aided design, which provides the three-dimensional product geometry. To find out where a hybrid workstation can support the CAD work, this paper aims to answer the following research question:

**What use cases for a hybrid AR computer workstation in CAD workflows exist to support the product developers everyday work?**

To answer this question, the first step is an exploratory user study on the distribution of CAD activities. By observing users performing a typical design task, a basic understanding of the most common activities is gained. For these activities, existing research on immersive interfaces is screened for relevant applications that are transferable to the hybrid workstation. The findings are summarized in the eight use cases each of which proposes an appropriate hybrid AR interaction design for a specific CAD activity. Finally, the potential of the use cases is assessed in order to prioritise development.

# 2 RELATED RESEARCH

Research into AR applications for product development, specifically performing CAD tasks, has been carried out for many years. Different interactions modalities and integrations of real objects have been investigated. Nee at al. (2012) summarized AR applications in design and manufacturing with many of their examples dating back till the 1990s. They found various AR based design applications, such as Contruct3D (Kaufmann et al., 2000), providing basic modelling for geometry education and ARCADE (Ng et al., 2010) allowing users to generate CAD models combining virtual and real objects. More recent surveys focus on co-design in manufacturing (Wang et al., 2020), the usage of the Microsoft HoloLens (Park et al., 2021), and classification of industrial AR applications (Siewert et al., 2021). They provide a comprehensive collection of the research activities concerning augmented reality interfaces for product development.

In contrast, hybrid interfaces combining conventional two-dimensional and spatial modalities are more sparsely researched. An early one is the three dimensional PC by Liu et al. (2001). They proposed a multimodal workstation based on an autostereoscopic display, combining conventional input with head-, gaze-, and hand-tracking into a 3D user interface supported by speech recognition. Later, Bornik et al. (2006) showed an interface for volumetric medical data combining a tablet PC with a

stereoscopic projection and using a custom handheld input device for both modalities. Steinicke et al. (2007) published a 3D interaction framework for everyday working environments, again using an autostereoscopic monitor with spatial and conventional input combined. Lately, Reipschläger and Dachselt (2019) extended an 2D interactive touch and stylus activated display with AR capabilities.
Hybrid interfaces specifically for CAD started with Stark et al. (2010) studying conceptual design going back and forth between a VR-Cave and a desktop PC. Wang et al. (2011) used markerless hand tracking to enable spatial assembly modelling on a 2D screen. Similarly, Song et al. (2014) employed hand gestures coupled with gaze control to manipulate CAD models. Fechter et al. (2014) proposed an intuitive hybrid modelling system using a VR head-mounted display (VR-HMD) and a PC. Millette and McGuffin (2016) developed the most similar interface to the hybrid workstation, DualCAD. Using a see-through AR HMD and conventional PC, a simple CAD software was developed with both a conventional WIMP (Windows, Icons, Menus, Pointer) interface and an AR counterpart. Only a button press in the desktop program is necessary to switch between the two modalities.
Only a few of the presented works actually make use of conventional and spatial methods for both the input and output of the interface. The works that are truly hybrid in this sense, still force the user to move back and forth between the modalities thus working sequentially and not parallel. The goal of this work is finding the use cases that truly leverage the strengths of both modalities concurrently.

## 2.1 Hybrid AR computer workstation for virtual product development

Our vision including a technical concept of a novel AR computer workstation has been published and is summarized in this section (Harlan et al., 2022). The main idea is to add an immersive hologram for visualisation and direct interaction with the three-dimensional product data to the product developer's computer workstation. This immersive extension still allows the full usage of existing tools and periphery and aims to enable parallel working in both modalities. Figure 1 shows the vision of the hybrid AR computer workstation with its main features.

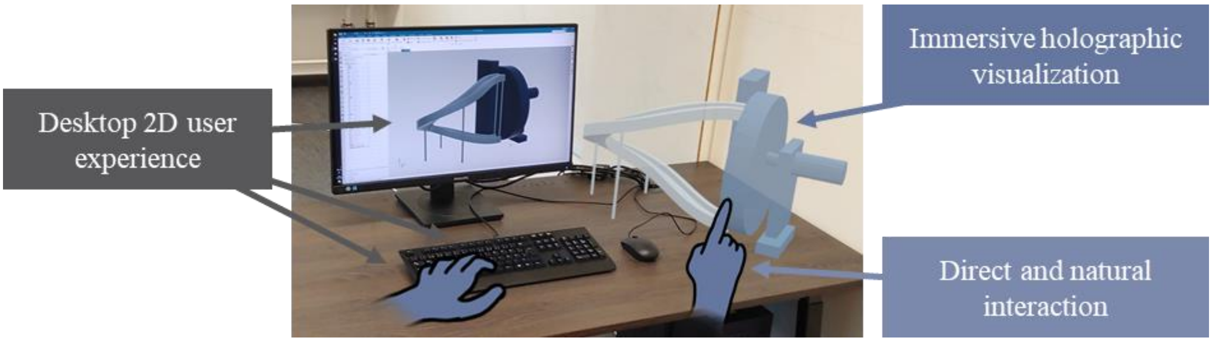


*Figure 1: Hybrid AR computer workstation*

A hard- and software concept of the hybrid AR workstation was developed. For immersive in- and output a head-mounted augmented reality see-through display (AR HMD) is worn while using the conventional desktop computer workstation, typically consisting of a monitor, mouse, and keyboard. Modern HMDs provide flexible hologram placement, high image quality, comprehensive development suite, and multiple sensors for user input, usually via head-, hand- and eye-tracking. For independence of battery life and performance constraints the glasses are tethered to the computer. All geometric processing and rendering is done on the workstation PC and send to the HMD. The integrated sensors allow for natural interaction with the hologram. With head-tracking, changing the user's perspective on the model is as easy as moving the head. Based on the hand-tracking, direct manipulations of the three-dimensional data can be achieved. The spatial bare-hand interaction could be supported with mid-air ultrasonic haptic feedback (Rakkolainen et al., 2019).
A conventional CAx software runs on the desktop PC and provides the well-know 2.5D interface and can be used in its full functional scope with the classic desktop periphery. The holographic interface is build using a game engine. These are well prepared to process all sensor data, implement the direct interactions and take care of the stereographic rendering (Harlan et al., 2020). A custom programmed protocol connects both applications running in parallel.
The tightly coupled spatial visualization and fast switching of modalities allow for the hologram to be integrated deeper into the CAD workflow than any other immersive interface before, creating true


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hybrid working conditions for the user. This fosters a faster execution of spatial tasks and better intuitive geometric understanding leading to improved design decisions and more user engagement.

## 3 CAD WORKFLOW ANALYSIS

To find the most effective use cases for the new hybrid workflows, it is first necessary to understand the frequency and duration of common activities in traditional engineering CAD work. Therefore, a small-scale user study was conducted. Four subjects, three mechanical engineering students and one draughtsman completed a simple modelling task in a CAD tool of their choice. The subjects had to create a simplified model of a curved chopping knife from a technical sketch with all dimensions given. The parts consist of common design elements and requires some assembly modelling. This way the users used the software the way they are used to without long thinking pauses. Using screen capture videos, the modelling process was split into CAD activity categories based on (Harlan et al., 2021) and (Lee and Yan, 2016). Because the users were used to their CAD tool and the task was quite simple, no thinking or idle time was noted. It is assumed that a started activity is done until the next one starts. The only exception is object selection, it can be part of other activities and only a timestamp is recorded.

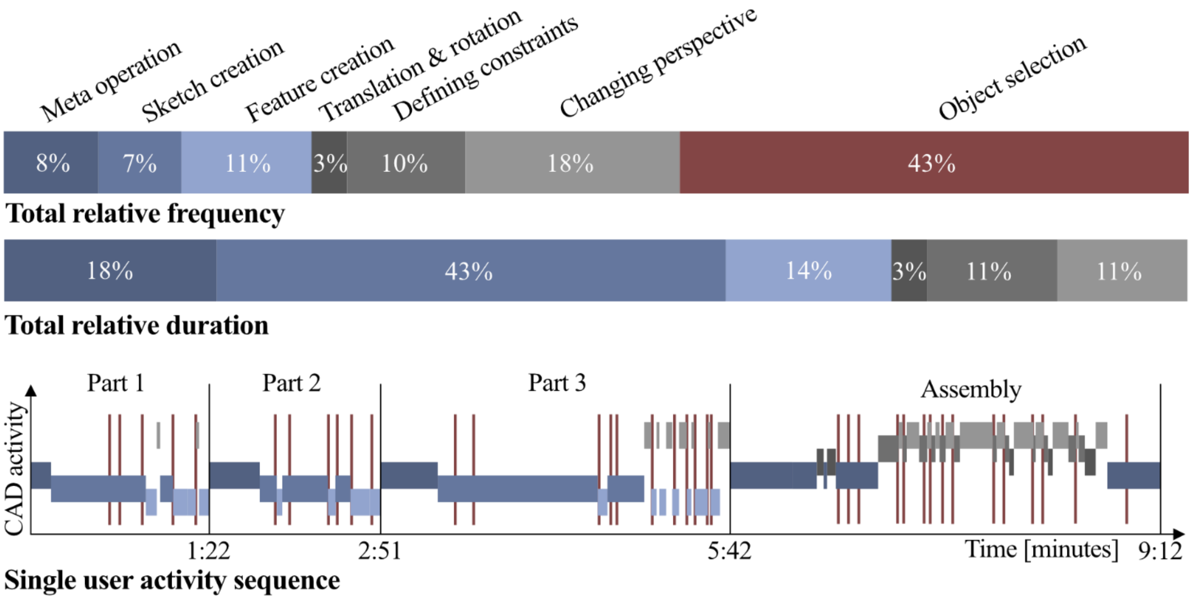


*Figure 2: Relative total frequency and duration of CAD activities of all users (top) Exemplary activity sequence of one user (bottom)*

The activity sequence of a single user is shown in Figure 2, bottom. First, the user models three separate parts with sketch generation and feature creation as the main activities. In the later stage the parts are assembled with a combination of part translations, constraint definitions and perspective changes. Meta operations, such as opening a new part or copying an existing one, are necessary to start each step. Object selections took place over the whole modelling process. Totalling the activity durations of all subjects, sketch generation took by far the most time for this simple assignment (Figure 2, top). Looking at the frequency, selection is the most frequent action, as it is part of many other activities. Also, the viewing angle is changed quite often and typically done in combination with a selection.

## 4 USE CASES FOR HYRID WORKFLOWS IN CAD

In order to find beneficial use cases for the hybrid AR computer workstation in CAD, the following method was chosen: First, the common activities from the user study are supplemented with drafting activities that are not covered by the study assignment but are part of design work. For these activities, the applicability of hybrid interactions was assessed using relevant literature and personal experience with immersive interfaces. Where appropriate, a hybrid interaction is conceptualised to support the activity. In this way, eight use cases for the hybrid AR computer workstation in CAD workflows were identified, sorted into three categories of activities: Fundamental, drafting and modelling CAD activities. Each use case is described in three paragraphs. First, the supported CAD activity is described with particular attention to the challenges encountered on conventional workstations. This is followed by a



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description of related research of immersive interactions for similar tasks. If no suitable research on AR interfaces was found, articles using VR with suitable input modalities are consulted. Finally, an approach is proposed to transfer the existing interactions to the hybrid AR computer workstation to support the activity. Additionally, expected benefits and implementation challenges are described.

## 4.1 Fundamental CAD activities

The most impactful use cases are those supporting fundamental activities used throughout CAD. Basic operations, such as object selection and transformation, are well researched using immersive environments. With a hybrid workstation, their benefits can be applied to the user's daily CAD workflow. Figure 3 shows two proposed use cases for fundamental CAD activities.

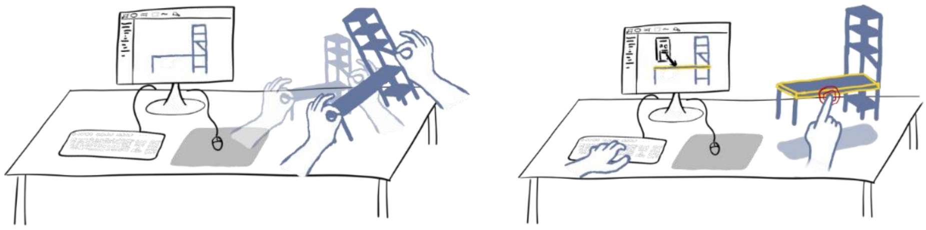

*Figure 3: Hybrid interactions for fundamental CAD activities:*
*Two-handed rotation, translation, and scale control for* ***immediate intuitive inspection*** *(left)*
*Touch interaction for* ***spatial object selection*** *(right)*

**Immediate intuitive inspection**

Throughout the use of CAD software, users view the 3D rendering of the part they are working on in the 2D viewport, making it a 2.5D interface. It is often necessary to change the perspective in order to inspect the current state and execute the next operation.

It has been shown that stereoscopic visualisation, especially with head tracking and intuitive object movement, significantly improves the understanding of three-dimensional objects (Satter and Butler, 2015). Direct virtual grasping is a natural interaction for object rotation and translation (Fechter et al., 2021). Mid-air bimanual interactions require a little more familiarisation, but in turn allow for more precision in rotation and additionally allow for control of object scaling (Song et al., 2012; Wang et al., 2011).

The hybrid workstation can provide an always up-to-date stereographic rendering. This allows an easy, intuitive and fast inspection of the current model. The user can simply look from the screen to the hologram and move their head to change perspective. A set of intuitive one- and two-handed interactions allows for quick repositioning of the visualisation. This use case requires only one-way communication between the CAD and hologram software, as no manipulation of the actual 3D geometry is performed. This makes implementation relatively straightforward. For a smooth user experience, a low latency between a change in the CAD and its reflection in the hologram is necessary. For large models, this poses a technical challenge.

**Spatial object selection**

As suggested by the user study, object selection is a common activity when working in CAD Software. Almost all higher-level operations need one or more elements as input or target operands. All kinds of design elements can be selected, depending on the operation, ranging from supporting elements like points, lines, and sketches, over geometry like corners, edges, and surfaces to complete parts.

Immersive three-dimensional selection is a well-researched subject, summarized by Argelaguet and Andujar (2013). A simple but proven effective approach is direct mid-air selection with the index finger (Lubos et al., 2014). In addition, modern consumer hand tracking hardware has been shown to be sufficiently accurate (Schneider et al., 2020).

For the hybrid workstation, a direct mid-air selection interaction is well suited, as all virtual objects are always located within an arm's reach. Every time the user wants to select an element, instead of using the mouse it is possible to lift the hand and quickly tap the element in the three-dimensional hologram with an index finger as shown in Figure 3, right. This spatial selection process would work the same way as in the desktop environments. The user can either select the objects to be modified before selecting the operation or the other way around. Like the geometry itself, the highlighting of selected elements should



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be synchronized between both visualization modalities. For this use case, good selecting heuristics with a well working collision volume and robust rules to differentiate between points, edges, etc. are necessary. Visual, auditive or even mid-air haptic feedback will improve selection confidence.

## 4.2 Drafting CAD activities

Drafting activities in early embodiment design require less precision and more creative freedom. CAD software is not well equipped for this, but immersive interfaces are. Thus, it is an active area of research and already exists in commercial VR software. For example, *Gravity Sketch* is a well-known VR tools that uses handheld controllers. By bridging the interface gap, the hybrid desktop environment allows users to apply similar methods to smaller creative tasks directly within CAD software. Figure 4 shows three proposed use cases for drafting CAD activities.

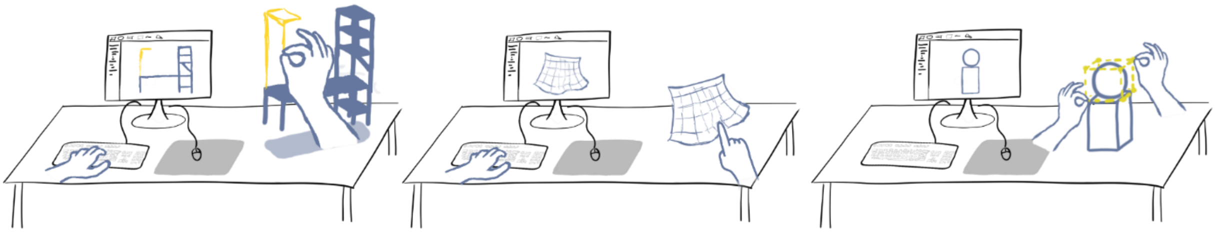

*Figure 4: Hybrid use cases for drafting CAD activities:*
*Line sketching for **three-dimensional annotating and sketching** (left)*
***Implicit manipulation of freeform surfaces** (centre)*
*Two handed **three-dimensional drafting with geometric primitives** (right)*

**Three-dimensional annotating and sketching**

In design reviews and early conceptual discussions the ability to quickly generate spatial sketches and propose changes directly on models supports communicating the participants' ideas. Simple line sketches can fulfil needs. They can be used to represent geometry, provide spatial hints when collaborating with colleagues, visualize dynamic behaviour or pose as small textual nodes.

Immersive 3D sketching has been shown to be a unique modality for geometry representation that combines behaviours from conventional drawing, CAD and physical models (Oti and Crilly, 2021).

To implement line sketching for the hybrid workstation, a pinch gesture can be used as shown in Figure 4, left. The immediate availability allows to quickly sketch ideas even within more detailed design phases. Furthermore, the keyboard could be used to activate the drawing with a button press instead of a gesture to improve temporal precision and prevent unintended movements. 3D splines can be used to store the sketches in the CAD file. These would have to be additionally synchronized between the two modalities, adding implementation complexity.

**Implicit manipulation of freeform surfaces**

Industrial product design focusing on the model's aesthetics deals mainly with freeform surfaces. For early conceptual phases, if the user is exploring different shapes and possibilities, the very precise nature of CAD tools is incapable of fast iterations in the modelling of these. Here, implicit modelling gestures allow for quick and intuitive realization of user's ideas.

Existing approaches create parametric surface patches from mid-air gesturing (Fuge et al., 2012) or spatial line sketches (Bhattacharjee and Chaudhuri, 2022). Researchers also developed an approach for 3D shape modelling from hand poses without predefined gestures (Vinayak and Ramani, 2015).

Applying these findings to the hybrid workstation could allow the users to intuitively manipulate freeform surfaces, as shown in Figure 4, centre. Since the existing approaches do not work directly on typical CAD data, intermediate geometric representations are required. The translations into CAD features make an implementation significantly more complex.

**Three-dimensional drafting with geometric primitives**

For early embodiment designs or quick suggestions in design reviews, drafting with adjustable three-dimensional geometric primitives such as boxes and cylinders can be a quick and easy way to communicate and iterate design ideas.

This method has been most commonly used with immersive interfaces. Commercial virtual reality modelling tools such as G*ravitySketch* provide the functionality. Researchers have developed



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bimanual natural interfaces (Fechter et al., 2020) and proposed a collection of natural interactions for the necessary modelling operations (Harlan et al., 2021).
A natural modelling interface could be directly adopted for the hybrid workstation to enable holographic CAD drafting, as shown in Figure 4, right. With the users focus on the 3D visualisation and two-handed interaction, the conventional interface would take on a more passive role. For example, it would allow inspection of the model tree, selection of primitives and insertion of comments.

## 4.3 Modelling CAD activities

Typical parametric CAD modelling activities require structured and precise work with the wide range of design features available. Here, fully immersive interfaces struggle to cover the required functionality in a professional software package and to provide suitable input options. However, there were research activities with focus on the support of specific CAD activities with immersive interfaces. By using a hybrid workstation, existing CAD software can be used to its full potential and enhanced with meaningful spatial interactions. Figure 5 shows three proposed use cases for modelling CAD activities.

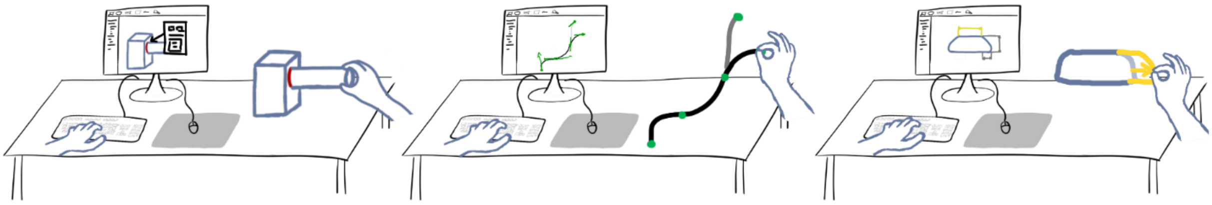

*Figure 5: Hybrid interactions in detailed design phases:*
***Natural assembly modelling** (left)*
***Explicit modification of parametric curves and surfaces** (centre)*
*Intuitive manipulation of design parameters for **natural parametric design** (right)*

**Natural assembly modelling**

Assembly modelling is a significant part of the CAD work, also suggested by the user study. Here, separately modelled parts are put together to create the final assembly. Usually, the parts are moved to roughly the right places and then necessary constraints are inserted to define the final positions.
Intuitive interfaces for this step have been researched using optical hand tracking in front of a conventional display (Wang et al., 2011), in augmented reality (Valentini, 2018), and virtual reality (Fechter et al., 2021). In all of these applications, parts can be picked up and arranged intuitively. The most common constraints are automatically recognised and inserted.
This procedure can be directly transferred to the hybrid workstation as shown in Figure 5, left. In particular, the 3D placement in the conventional interfaces using widgets is tedious and can be significantly improved, as shown by (Fechter et al., 2021). The automatic constraint suggestions could be accepted or adjusted in the conventional interface making the method more robust for all situations.

**Explicit modification of parametric curves and surfaces**

Parametric curves or surfaces defined by control points such as non-uniform rational basis splines (NURBS), are a common CAD data. If the desired shape is truly three-dimensional, the modelling of such features can be particularly difficult with conventional interfaces.
Immersive interactions to manipulate the control points intuitively were explored with hand tracking (Cohen et al., 2019) and a haptic input device (Valentini and Biancolini, 2018). Furthermore, a suite of bimanual interactions to create a curve network was proposed (Lee et al., 2022).
Using the hybrid workstation would allow for direct spatial manipulation of control points by grabbing them with a pinch gesture, as shown in Figure 5, centre. This can help the user adjusting such features intuitively. While the interaction itself is straightforward to implement, a live preview of the changed geometric feature in the hologram is not.

**Natural parametric design**

Parametric design is a typical method of creating CAD geometry. The user defines sketches using mathematical formulae. Based on these, geometric features such as extrusions are created. For complex models with many parameters, it can be difficult to make the right changes to achieve the desired results, especially for non-experts.



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Immersive interfaces have also been researched to provide drastically new ways to create and manipulate parametric features. For example, direct extrusion (Bourdot et al., 2010) and spatial manipulation of shapes with automatic parameter inference (Okuya et al., 2018) have been explored.
In a hybrid setup, such interactions would allow natural manipulation of a parametric part by grasping and reshaping its surface in the hologram, as suggested in Figure 5, right. Internally, the necessary parameter changes must be inferred and reflected in the conventional software. Furthermore, some operations of the direct modelling paradigm can be translated to spatial interactions. For example, an extrusion could be triggered when a sketch on a surface is pinched and pulled outwards.

### 4.4 Assessment

Complementing the proposed CAD use cases for the hybrid AR computer workstation, their applicability is assessed in four characteristics and the results are shown in Table 1. The impact on CAD workflow is derived from the study results in section 3. The drafting activities are not covered by the study assignment and are therefore left blank. The effectiveness describes how well the proposed interactions would work. This includes available empirical results and personal judgement. The suitability for hybrid workstations describes how seamless the spatial interaction would be embedded in the conventional workflow. Finally, the implementation complexity reflects the effort required to implement the interaction. Additional necessary algorithms or intermediate data structures decrease the judgement. Because the proposed eight use cases are already the ones deemed to be applicable for the hybrid AR workstation, none of them are ranked bad in one of the first three characteristics (Impact, Effectiveness and Suitability).

*Table 1: Overview of the presented use cases with assessment of their impact on CAD workflow (Im), effectiveness (Ef), suitability for hybrid workflow (Su), and implementation complexity (Co) on a scale from good (+) to bad (-).*

| CAD activities | Use case | Im | Ef | Su | Co |
|---|---|---|---|---|---|
| Fundamental | Immediate intuitive inspection | ○ | + | + | + |
| | Spatial object selection | + | + | + | + |
| Drafting | Three-dimensional annotating and sketching | | ○ | + | ○ |
| | Implicit manipulation of freeform surfaces | | ○ | + | - |
| | Three-dimensional drafting with geometric primitives | | ○ | ○ | ○ |
| Modelling | Natural assembly modelling | ○ | + | ○ | ○ |
| | Explicit modification of parametric curves and surfaces | ○ | ○ | + | ○ |
| | Natural parametric design | + | ○ | ○ | - |

## 5 CONCLUSION AND OUTLOOK

In this work eight use cases for the hybrid AR computer workstation for in CAD work are presented and their applicability assessed. A small study was conducted to find out which CAD activities are most commonly done. While for most activities a use case was proposed, for the most time-consuming activity, sketch creation, no specific hybrid use case is presented. This is due to the fact, that in its conventional form, it is an inherently two-dimensional task that requires precise input and is thus not suited to immersive interfaces.
Besides CAD, there are many more activities within virtual product development dealing with three-dimensional product data which might also benefit from the usage of the hybrid AR workstation. Further investigations into CAE and CAM for example should be done. The fundamental use cases presented in this paper should be applicable as well and new specific ones might be found.
The next step is to implement this novel interface. Most of the necessary software elements have already been tested (Harlan et al., 2020), but several challenges remain. These include the quick synchronising of the geometry of large models, the handling of input in the game engine while keeping the CAD window in focus, and the efficient integration of the functionality into the control flow of a commercial CAD tool, to name a few. When the software coupling is implemented, first evaluations of the comfort and helpfulness of the immediate spatial inspection can be carried out. The biggest question is whether or not wearing AR Glasses at the computer workstation hinders the conventional PC usage. While the glasses are see-through and balanced in weight, it might still cause discomfort wearing them for longer periods of time. From there, it is possible to implement the interactions for the presented use cases. We see the


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biggest impact through spatial selection, as it is the most frequent single action in the small study. This should be confirmed in a formative expert study with the first prototype working. An implementation of a hybrid interaction has to provide quick, precise, and confident results for it to stand a chance in empirical comparison with their conventional variant.

If the challenges are overcome, this novel workstation and the presented CAD use cases have the potential to be integrated smoothly into everyday work, similar to touch screens on laptops, where users can intuitively decide if they use their hands on the screen or on the the trackpad. 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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