

SPATIAL FUTURES STUDIO: Cooperative MR Design-Production

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Milgram and Kishino define mixed reality (MR) through their concept of a “virtuality continuum” that spans between real and virtual environments, wherein display technologies are configured to combine real objects and computational models.¹ With augmented reality (AR) towards one end of this foundational spectrum and virtual reality (VR) establishing the other, Azuma defines AR as real-time systems that combine the real and virtual, with registration in three-dimensional space.² Generally, MR applications utilize location-specific information for spatial registration.³

MR has begun to permeate a wide range of fields from medicine⁴ and cultural heritage,⁵ for example, to Architecture, Engineering and Construction (AEC) sectors.⁶ Additionally, MR applications are evolving as key components of digital ecologies associated with the Construction 4.0 framework.⁷

While MR applications have been widely used for design visualization and review,⁸ a sampling of the current state of research in MR architectural production illustrates a promising set of emergent prospects and implications. AR applications and workflows have been implemented for holographic masonry construction,⁹ human-robotic timber fabrication,¹⁰ complex assembly¹¹ and handcraft-based MR fabrication plus interactive component design for large-scale steam-bent timber structures.¹² Notably, MR-based fabrication can rapidly facilitate complex component fabrication and large-scale assembly by unskilled workers.¹³ Additional collaborative advantages have been demonstrated through research in hybridized MR design and production.¹⁴ This body of work demonstrates how MR offers a multitude of transformative potentials for architectural education and future practice, as it distinctively provides expanded access to substantive engagement in

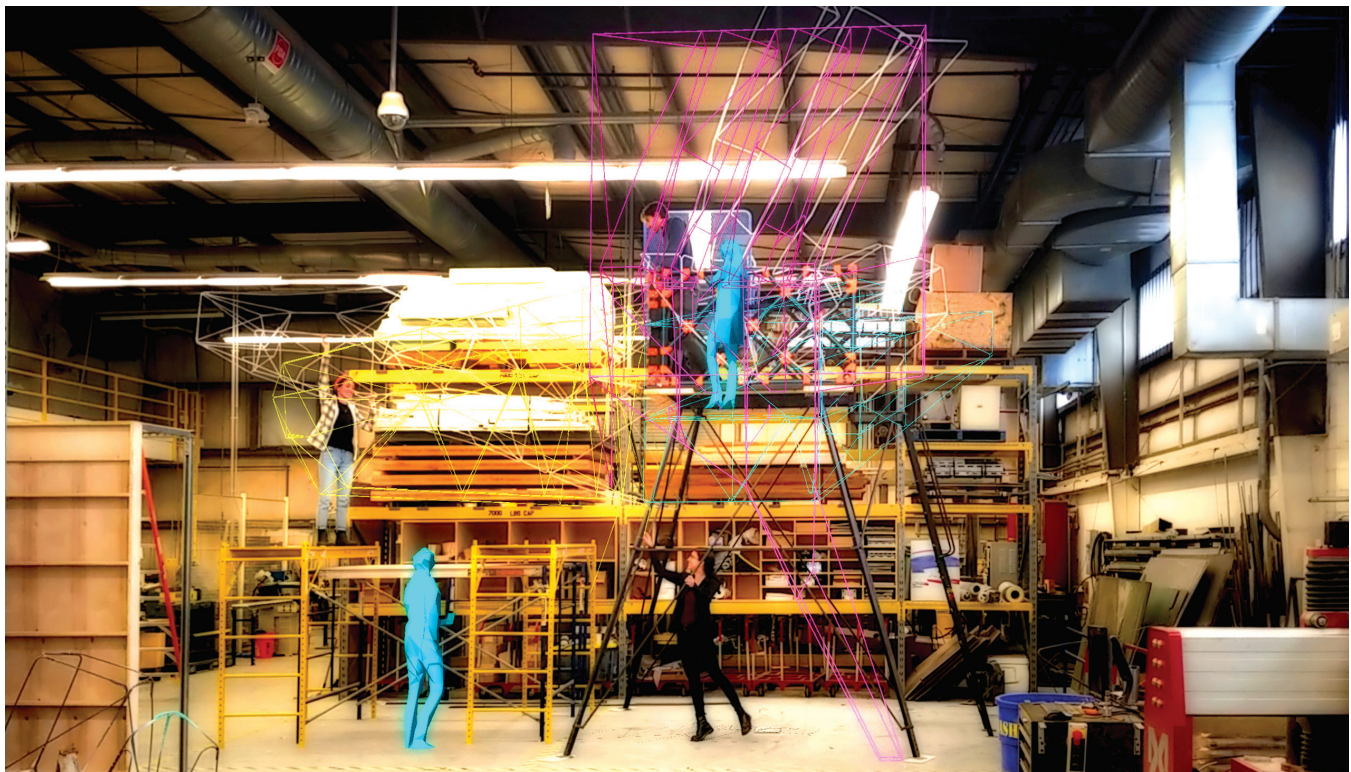


Figure 1. *Beacon Armature* as a live working platform in progress as seen through AR on a phone: installed (white) spatial components are overlaid with virtual components (magenta, yellow) yet to be refined and produced. Spatial Futures Studio.



Figure 2. Final installation of *Beacon Armature*, with spatial frame components designed, fabricated, assembled and installed through MR-based approaches. Spatial Futures Studio.

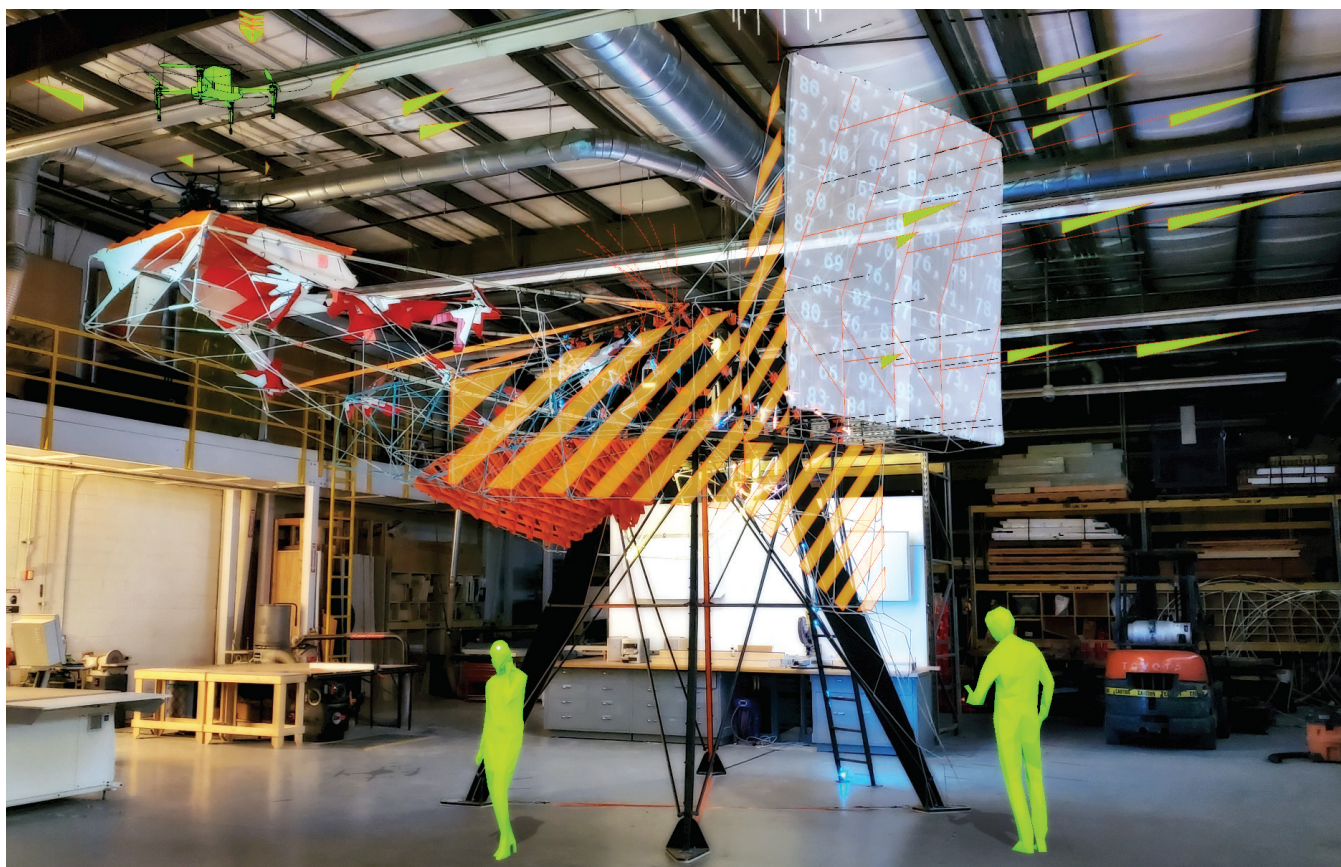


Figure 3. Composite view of an AR application designed to register spatial information to the completed *Beacon Armature*. Spatial Futures Lab.

design and production processes for participants entering with a wide range of skillsets and insights.

SPATIAL FUTURES STUDIO

Spatial Futures Studio was launched in 2019 as an experimental design and research studio calibrated for full commitment to cooperative MR production utilizing available technologies and proven approaches as its base operational platform. Configured as a collective endeavor with eleven students who had no prior knowledge of MR-based production and only a few of whom equipped with previous experience in shop production, AR applications served as the primary conduit for design communication, fabrication, and assembly of large spatial assemblies. A semester-long exploration of working modes and outcomes uniquely achievable through MR, key questions centered on the ease and effectiveness with which collective command of the approaches at hand would be reached such that cooperative work would fluidly oscillate between design ideas and spatial action throughout all stages.

Consolidating a cantilevered drone landing pad, elevated billboard and occupiable deck as its key architectural features, *Beacon Armature* is a full-scale construct that served multiple purposes through the progression of the studio. As a working armature (Figure 1), it provided the core design initiative

organizing all permutations of collaborative spatial development while prompting iterative material explorations during its evolution. In its finalized state as a typological prototype, *Beacon Armature* is an architectural actualization to be experienced both in its own terms (Figure 2) and through AR applications (Figure 3).

Establishing the goal of producing one full-scale architectural construct and a small collection of large-scale “mega-models” at the outset, thousands of feet of $\frac{1}{4}$ ” diameter steel rods, a hand-operated rod bender, a prefabricated structural platform and a Microsoft HoloLens equipped with Fologram were provided to the students. Released in 2018, Fologram is a commercially available software platform that couples Rhino and Grasshopper with the Microsoft HoloLens, phones, and tablets for live AR interactivity¹⁵.

Utilizing established methods¹⁶ and modifiable computational definitions provided by Fologram, the essential MR-based fabrication approach for this project involved hand bending steel rods into complex components. In this process, a fiducial marker spatially registers digitally modeled component geometry to a hand-operated rod bender (Figure 4) and is displayed within the HoloLens. An AR interface allows the operator to align and bend a steel rod with this virtual guide, use a hand



Figure 4. MR-assisted manual steel bending. Spatial Futures Studio.

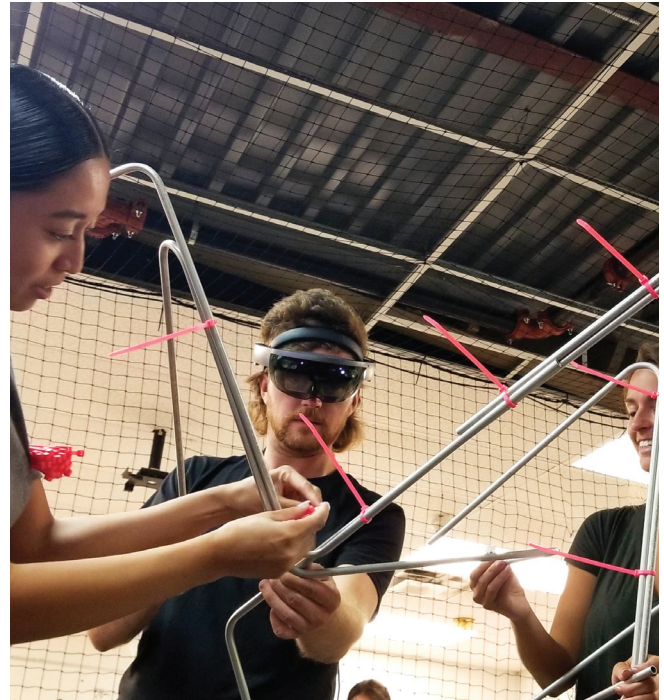


Figure 5. Day one MR assembly training. Spatial Futures Studio.

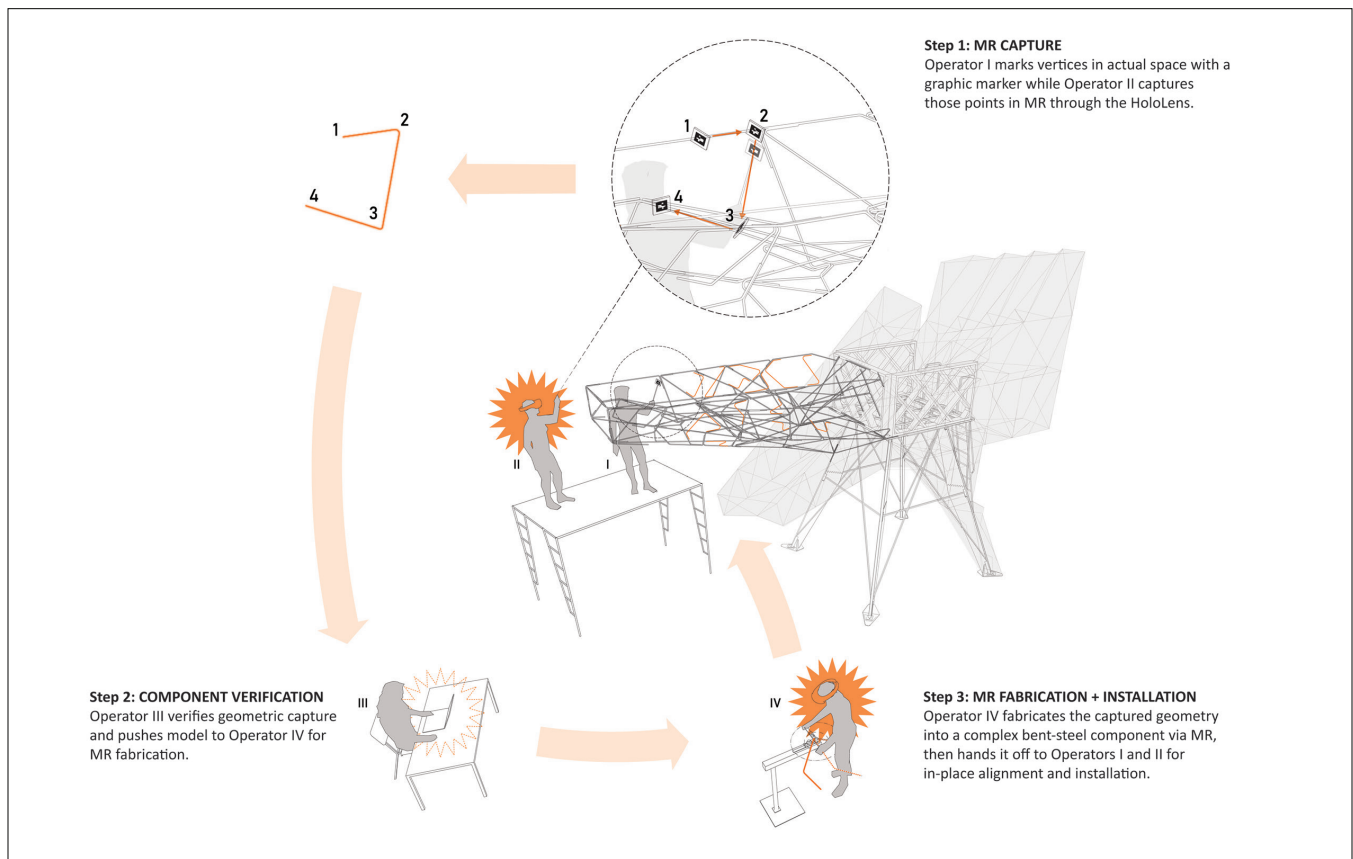


Figure 6. Cyclical cooperative AR workflow utilizing Fologram to simultaneously bridge virtual and actual space for rapid design, fabrication and installation of complex components in place. Spatial Futures Lab.

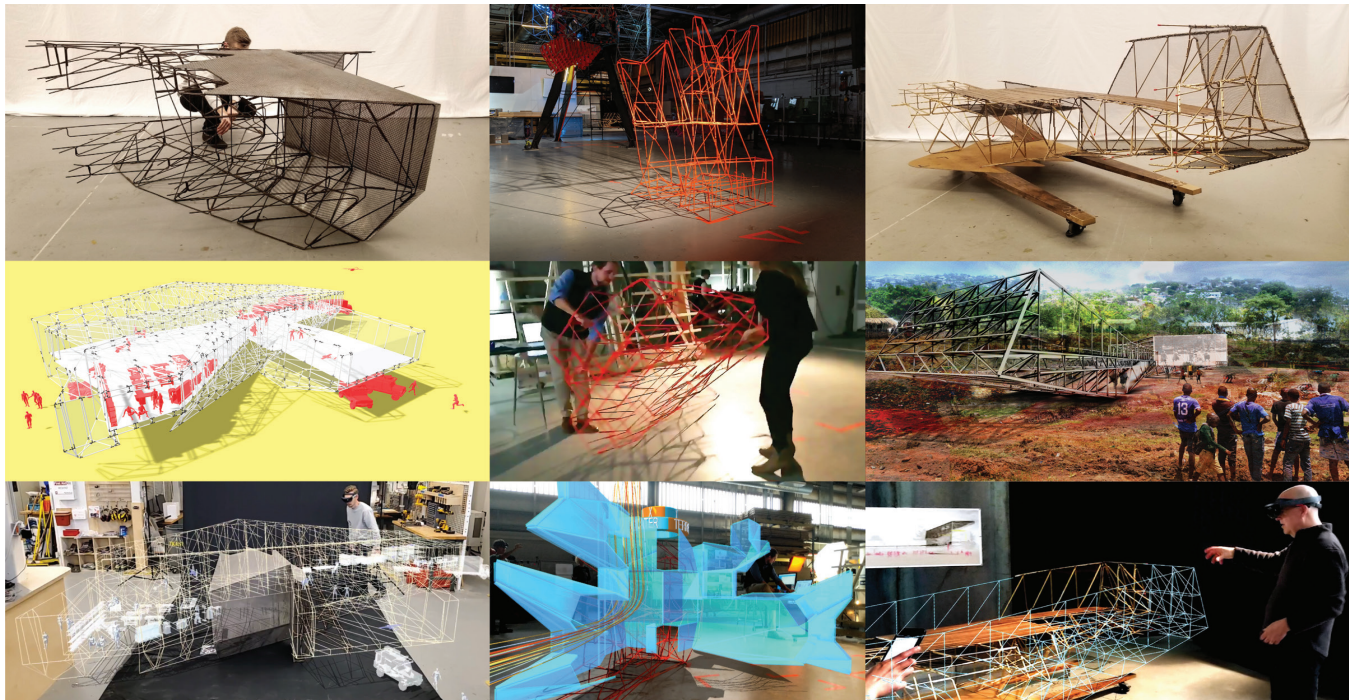


Figure 7. *Mega-Models*: architectural projects developed in the final weeks, fabricated and communicated through MR. Spatial Futures Studio.



Figure 8. Spatial Futures Studio operated as a fluidly dynamic MR-based cooperative practice, producing a wide array of operational insight and spatial evidence through its experimental approach. Spatial Futures Studio.

gesture to select a new virtual guide for the next required bend, realign the bent steel and perform the next bend, then repeat all steps until the piece is completed. Completed pieces are then assembled into larger spatial components utilizing AR displays to guide their proper placement in space.

Training in MR production commenced on day one (Figure 5) and soon thereafter students were designing and producing large welded assemblies. Nuanced AR workflows emerged as work transitioned to larger scales involving complex coordination. Various operational clusters ranging in size from an individual operator to teams of five revealed situations where it proved to be beneficial to have one team member wearing a HoloLens orchestrating a crew of assemblers, for example, while other scenarios relied upon simultaneous use of multiple devices. A key workflow involved the stiffening of a large cantilevered spatial component upon its AR-based prefabrication and installation, wherein a four-person team rapidly configured, fabricated, and installed new complex components through a live design process that simultaneously inhabits actual and virtual space (Figure 6).

With only several weeks remaining in the schedule, three separate architectural projects were conceptualized and designed as frameworks for civic beacons in their own terms. Utilizing techniques and materials outlined above, participants produced three 1:10 scale section models through the collaborative agility and MR dexterity cultivated within the studio up to that point. AR applications registered to these models provided the prime communication interfaces for spatial, structural, and situational ideas tied to each project (Figure 7).

CONCLUSION

Spatial Futures Studio is a demonstration in cooperative MR spatial production (Figure 8). Performed by novices at a rapid pace, it leverages AR approaches towards the design and material realization of projective architectural ideas and large-scale spatial constructs. Produced through a host of nuanced MR-based workflows and operational dynamics, the resultant work further points to the prospective emergence of MR as a transformative arsenal for future modes of cooperative architectural education and practice. Utilizing MR through all studio phases sparked a vigorously productive working atmosphere in which digital models, physical materials, ideas, and actions were continuously intermingled in both virtual and actual space. Perhaps most importantly, this setup fostered participatory equity such that every player was able to customize and flex their own mix of intellectual, spatial, labor, and communicative contributions to the complex cooperative MR design-production endeavor.

ENDNOTES

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