DYNAMIC PROJECTION

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Abstract. Rarely are technologies of projection mapping (PM) and mixed reality (MR) used together with an architectural agenda. Dynamic Projection imagines the confluence of accessible PM and MR technologies and asks "How might we leverage the strengths of both technologies while obviating their weaknesses?" And then "How might this technology be of use in making architecture from within the Climate Movement?" First, we will examine the dormant potential of Projected MR by augmenting a physical model in an exhibition setting. The exhibition set-up deploys Unity and Vuforia to generate MR, and Mad Mapper to generate a projection mapped background space. Using this set-up reveals strengths in both technologies, which we can evaluate with a Cybernetically Enhanced Mixed Reality Framework. We can leverage this Projected MR as a suite of tools to make architecture a more active participant in the Climate Movement: for example, by augmenting buildings with statistics that could help reduce energy consumption or through the augmentation of the construction process, helping facilitate waste reduction through efficient construction. Our initial research is being expanded through development of a more versatile Projected MR platform with Dynamic Projection 02, in which we are utilizing better MR tools, more responsive PM tools, and an industrial robot to simulate various dynamic feedback systems. This expanded research design speculates on a 3-part exhibition that can respond with low latency via Projected MR controls during a public and private interactive experience.

Keywords. Projection Mapping; Augmented Reality; Projected Augmented Reality; Cybernetics; Mixed Reality; Responsible Consumption and Production; Climate Action; SDG 12; SDG 13.

1. Introduction

Mixed Reality (MR) (often used interchangeably with Augmented Reality) and Projection Mapping (PM) are related but markedly different technologies used to overlay digital information onto real-world objects. Using different strategies, both mix the real and the virtual to varying degrees. Projection Mapping casts light onto objects to augment them with virtual effect, while MR typically relies on a handheld, or head mounted prosthetic to align virtuality with reality. This paper investigates the latent

POST-CARBON, Proceedings of the 27th International Conference of the Association for Computer-Aided Architectural Design Research in Asia (CAADRIA) 2022, Volume 1, 39-48.

affect of the layering of Projection Mapping with Augmented Reality. Using recent expansions and reframing of two important conceptual frameworks, Cybernetics (Wiener 1948), and the Reality-Virtuality Continuum (Milgram et al. 1995) allows us to reassess previous Mixed Reality research in architecture, and better position future research moving forward.

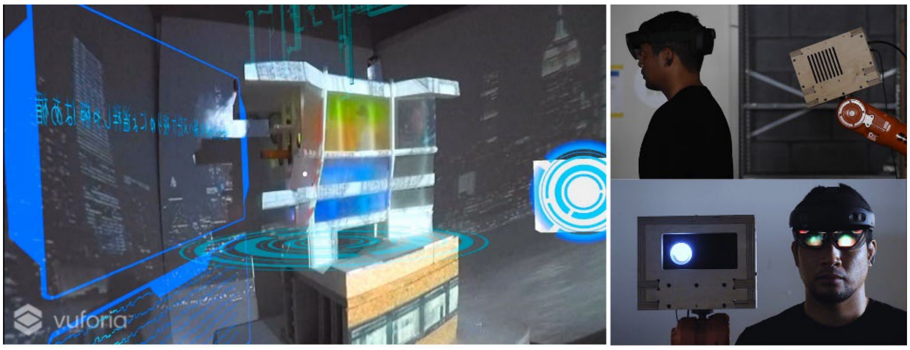

Figure 1: Augmented Reality and Projection Mapping Overlayed on Exhibition Object, and Dynamic Projection Elevations

1.1. MIXED REALITY FRAMEWORK AND CYBERNETICS

In a formative study, Paul Milgram and a team in Toronto developed a continuum of Reality-Virtuality that has since become a keystone theory in the field of Mixed Reality and Human-Computer Interface (Milgram et al. 1995). This work was recently reappraised through a comprehensive analysis of 68 peer reviewed papers about Mixed Reality (MR), and via interviews with ten Augmented Reality/Virtual Reality authorities in Academia and industry, providing an updated understanding of how these experts define MR (Speicher et al. 2019). The recent analysis adds depth to the MR Continuum by proposing 6 definitions of MR (Table 1, Column 1) used by experts in the field, and then constructing a conceptual framework of MR features that allows us to unambiguously describe MR experiences (Table 1). This framework describes specific variations of MR and provides readily usable attributes for categorizing MR experiences.

The key parts of a communication theory of Cybernetics can be aligned with our query into PM and MR by examining them through the lens of Speicher et al.'s work. Wiener's original Cybernetic theory has been summarized as being

> "...concerned with system models in which some sort of monitor sends information about what is happening within or around said system at a given time to a controller. This controller then initiates whatever changes are necessary to keep the system operating within normal parameters." (Lasky 2020).

We here propose an additional dimension (grey columns in Table 1) to identify a relationship between the Cybernetic Dimensions of input and output, or the Monitor and the Controller. Using this framework, we can now further investigate how PM and

MR behave differently at the communication and control level – allowing for better research design.

Dimension	No. of Enviro-nments		No. of Users		Level of Immersion			Level of Virtuality			Interaction		Mon-itor/ Feed-back	Res-pons e	Feed-back Relatio nship
Value	A	B	A	B	C	D	E	C	D	E	F	G	H	H	H
1. Continuum	✓		✓		✓	✓	✓		✓	✓	✓		✓	✓	✓
2. Synonym	✓		✓		✓	✓			✓		✓		✓	✓	✓
3. Collaboration	✓	✓		✓		✓	✓		✓	✓	✓	✓	✓	✓	✓
4. Combination	✓		✓			✓	✓		✓	✓	✓		✓	✓	✓
5. Alignment		✓	✓		✓	✓	✓	✓	✓	✓	✓		✓	✓	✓
6. Strong AR	✓		✓			✓			✓		✓	✓	✓	✓	✓

Table 1: Cybernetically Enhanced Conceptual MR Framework (Speicher et al. 2019, Wiener 1948)

A. One; B. Many; C. Not; D. Partly; E. Fully;
F. Implicit; G. Explicit; H. Any, Grey: Cybernetic Enhancement

2. Objectives

By aligning definitions of MR from the field of Human-Computer Interfaces with our own architectural research, this paper seeks to counter the growing uniformity of research projects around the field of architectural MR. Further, by using this method to unambiguously classify various types of MR, we can help guide future architectural MR research, and begin to develop uses and modes of action that can have immediate real-world consequences.

Advances in BIM, Facebook's Metaverse, and technology of the like; will lend themselves to hybrid information systems, Architectural design and construction will necessarily tap into these definitions of MR. Our research aims to provoke an awareness of the utility of hybrid information technologies for sustainable construction methods, efficient design, and climate-change related management of construction, among others.

Finally, by aiming to pull AR/MR functionality back from the interior, private world of prosthetically-enhanced interactions, we hope to privilege and address the actual, physical world of climate change, hunger, waste, and politics. We challenge future researchers to use this framework to judge their own work and its impact on sustainable development.

3. Background

3.1. INTERACTIVE PROJECTION MAPPING

For many years, interactive PM has been the subject of academic research framed for the entertainment industry. This has included a low-latency, room-filling multi-projector set up to play handheld controller video games (Ryu et al. 2006); a Dyadic Projected Spatial Augmented Reality that allowed a pair of users at fixed perspectives to interact with 3D spatial projections without the need of hand-held or head-worn prosthesis by using three video projector–Microsoft Kinect Rigs (Benko et al. 2014); and on a smaller scale, a hand gesture based holographic 3D modeling experiment that leveraged a single projector, semi-reflective screen and Leap Motion sensor (Johnson and Teng, 2014). When evaluated using the Cybernetically Enhanced Conceptual MR Framework (Table 1) these projects show use-cases of an interactive mixed reality that are: heavy with implicit interaction; single environment; single and multi-user; partially-fully immersive; partially-fully virtual, both implicitly and explicitly interactive, and have a cybernetic loop with feedback monitors and response. These dimensions are characteristics of interactive projects that could lead to richer experiences for users of MR devices and are the ones we are pursuing with our Dynamic Projection research.

3.2. MIXED REALITY/AUGMENTED REALITY

Typically, AR/MR research is focused on enhancing fabrication processes that liberate the construction process from 2D drawings, allowing for the fabrication of complex 3D forms. Fologram – a software plug-in for Rhino 3D and Grasshopper applications that facilitates the building instructions and geometry streaming in mixed reality to precisely track the bending steel, and steam bending of wood into curvilinear shapes, is a common tool (Jahn et al. 2019). Others have leveraged custom-built apps using Vuforia, a plug-in for Unity, to visualize step-by-step instructions through a HoloLens and iPhone, aiding the construction of his space frame structure and panelization for his thesis project (Gopel 2019). Still others have applied AR using real-time motion tracking cameras like OptiTrack and Kinect to track progress of diverse construction methods (Hahm 2019).

These types of deployments of MR/AR technologies are exemplary of current research, revealing a uniformity of methodology and objectives (MR/AR used as a set of 3D instructions to assemble atypical forms). Examining these MR/AR projects using the Cybernetically Enhanced Conceptual MR Framework (Table 1), we can see that all these projects are: single environment; single-user (one person controlling); partially-fully immersive; partially-fully virtual, both implicitly and explicitly interactive, and have a cybernetic loop with feedback monitors and response.

These projects rely on interactions between the MR interface and physical reality – and the AR artifacts only exist in the MR/AR interface unless acted upon. Thus, interactions in the MR/AR digital world remain in the MR Prosthetic until an operator acts on the objects in the physical world. Understanding this limitation offers a ripe opportunity for architectural MR/AR researchers to create systems that utilize the MR interactions of multiple users, facilitating a control-monitor-output loop via Projection Mapping, and building tighter ties between virtuality and reality.

4. Methods

4.1. MODEL DESIGN AND EXHIBITION SET UP

Our initial research centred on the design of an exhibition object for MR/AR experimentation. We began with a 1/16” = 1’-0” scale architectural chunk model of a waste-to-energy Facility in Brooklyn NY. This object let us study different applications for projection mapping, with some applications directly scalable to real buildings. The chunk model was fabricated with concrete, PLA, and frosted acrylic to emulate a photo-receptive media facade that allows for advertisements, art, videos, and waste-to-energy statistics to be projected onto the facade (Figure 4).

The exhibition was installed with our model and a plain backdrop. A Lightform LF2 projector end effector was attached to an ABB IRB1600 robotic arm housed in a plywood enclosure. Using a 6-axis arm to hold the projector allowed us to accurately engage different projection angles, memorized by our Software Control Computer. More than one operator could experience the additional layer of MR on the exhibition model using their own MR prosthetic - in this case a HoloLens or iPhone (Figure 3).

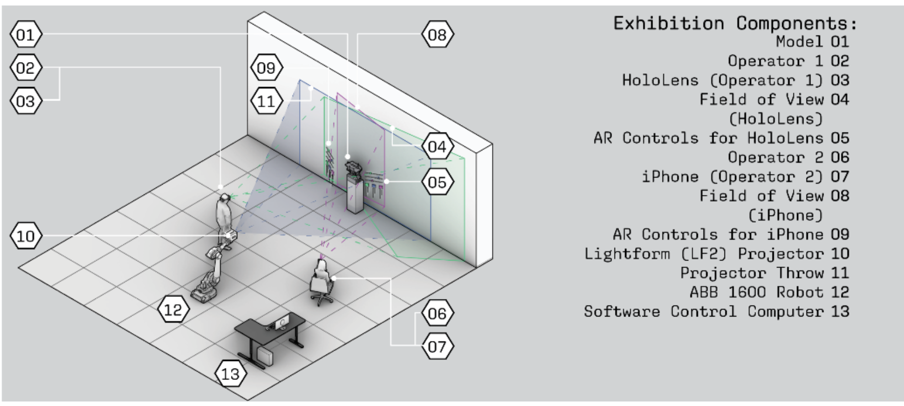

Figure 3: Exhibition Set Up for Dynamic Projection

4.2. PROJECTION MAPPING

Our initial setup provided a visual, but not interactive experience. We then added interaction between the software and the users. Looped videos and still textures were projected on the model to set ambiance and animate the exhibition object. We used Mad Mapper 3.7.4 to manage the textures and animations. Figure 4 shows the plain object and the projection mapped object. Metal texture was mapped onto the PLA of the model (Figure 4.05), allowing us to see how different facade systems may present themselves. The media facade shows beverage advertisements (Figure 4.08), waste-to-energy infographics (Figure 4.07), tech advertisements (Figure 4.10), and a baseball game (Figure 4.09), among other things.

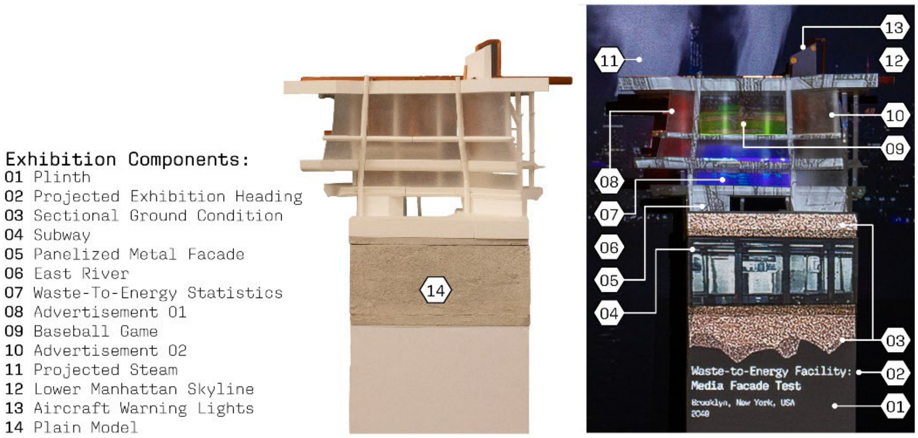

Figure 4: (Left) Plain Model, (Right) Projection Mapped

4.3. MIXED REALITY

The MR set up in Dynamic Projection was discrete from the PM being deployed. We used Vuforia 9.8.8 and Unity 2019.3.6.1 to make a custom application for the MR devices (iPhoneX and Hololens2), allowing a single user to pull additional visualization from a digital model in Unity. These custom applications use a 3D target marker generated by Vuforia to align the digital media with the real world, allowing interactions between the operator and digital model to take place. We populated the MR with a series of animated placeholder texts filled with information about the exhibition and a button (Figure 5) that toggles between exploded views of the Mechanical and Structural assembly holograms.

5. Discussion

5.1. DYNAMIC PROJECTION

The first iteration of Dynamic Projection uncovered latent potential by combining the mixed reality method of PM and MR Prosthetics. Using the Cybernetically Enhanced Mixed Reality Framework (Table 1) to analyse our exhibition set up revealed the following aspects of MR: multi-environment (discrete Projection Mapping and MR digital environments); single and multi-user (multiple users each using their own MR Prosthesis but sharing the same Projection); partially-fully immersive; partially-fully virtual, both implicitly and explicitly interactive, and have a weak cybernetic loop with feedback monitors and response.

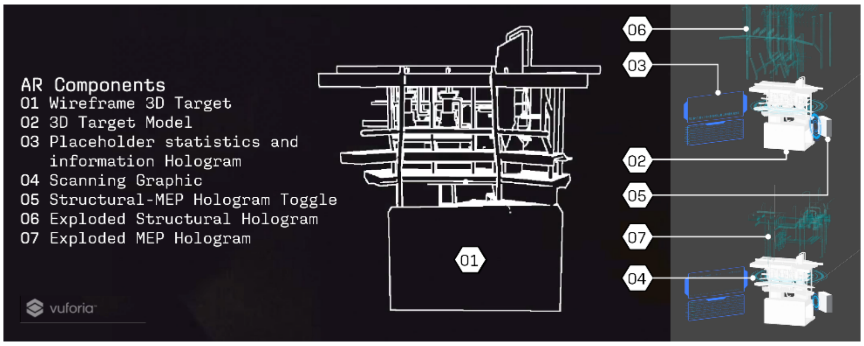

Figure 5: - MR Schematic

Dissecting this set up, we see a loose-to-no connection of PM to MR. MR interactions are only visible via prosthetic, and PM scenes, while visible without prosthetic, cannot change once Dynamic Projection is in action. We see potential for improving multi-user experience through multiple MR devices interacting with the same object in a shared environment tied together with PM. The combination of PM and MR in an interactive Projected Mixed Reality platform could be deployed at an architectural scale.

Scaled up to architecture, we posit that Dynamic Projection could make architecture a more active participant in addressing the systemic injustices of climate change. At the construction stage of architecture, we can see a Dynamic Projection set-up as an interactive, re-orientable version of previous projector assisted fabrication experiments (Ahn et al. 2019). This could minimize construction waste by allowing laborers to more efficiently and responsibly cut down and dispense material, for example. Existing architecture could be transformed into a site for interactive media. Building facades could be outfitted with Dynamic Projection set-ups to make public facing and interactable displays of energy usage and other related information to help regulate energy consumption and even educate people interacting with the building.

5.2. DYNAMIC PROJECTION 2

5.2.1. Exhibition Set Up and Hardware Changes

For our current and future research, we utilize a similar exhibition set up. Dynamic Projection 2 focuses on the development of the interactive Projection Mapping and MR connection, imbuing positional tracking of the MR Prosthetics to inform our mobile robotics platform (Figure 6).

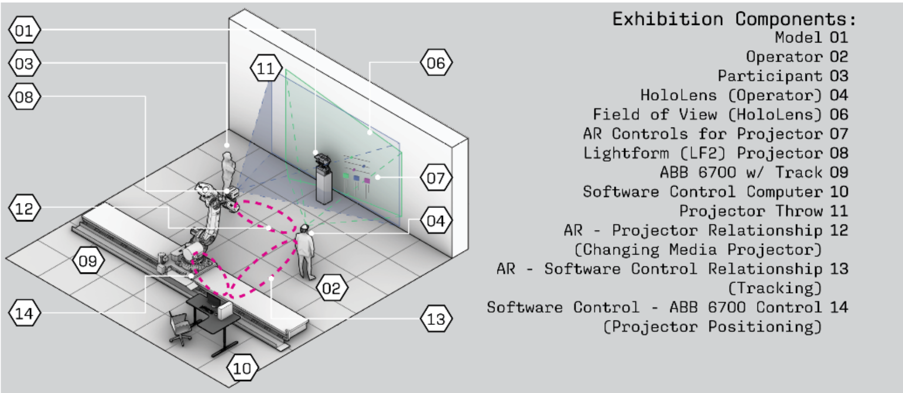

Figure 6: Proposed Layout for Dynamic Projection 02

The most prominent design-hardware change is the use of a much larger ABB IRB6700 on a 30-foot track to emulate the wider range of motion inherent in a variety of potential future setups. This development of AR controlled projection mapping will engender discussions for the private (HoloLens or phone) and public PM realms of this proposed system and will likely prompt investigations into this research that are both privately and publicly framed.

The new end effector we have designed is both big enough to enclose the projector and vented to keep air circulating where required. Vibrations could be further minimized by using a lighter material and rubber gaskets to dampen the shaking. We imagine the current box design of the end effector will remain largely the same for the next iteration (Figure 7).

5.2.2. Software Changes

Figure 6 shows a rudimentary layout for our intended MR interface. Built on Fologram: sliders and buttons will be used to encourage explicit interaction. For example, an MR slider interaction could move our robot in predetermined positions for alternate projection mapped scenes. An MR button could be used to switch between materials being projected onto artifacts, or toggle different information displayed in the background.

To aid the interactive PM, TouchDesigner will be used in lieu of Mad Mapper for its capability to communicate with Rhino3D/ Grasshopper via a communication plug-in called gHowl. Grasshopper will serve as the main platform that facilitates the communication between TouchDesigner and the MR interactions on Fologram.

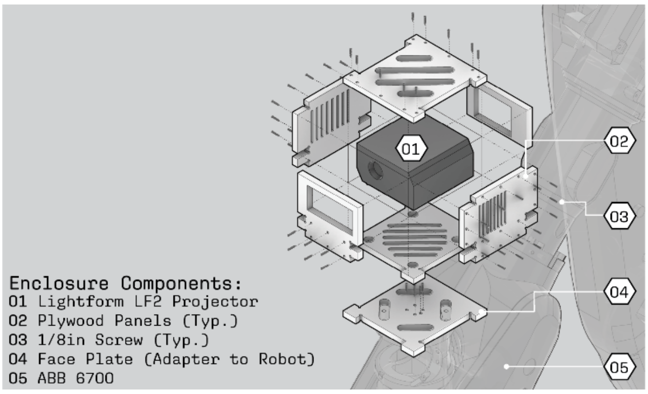

Figure 7: End Effector Enclosure

6. Conclusion

This paper presents a use case for the confluence of PM and MR technologies. Previous technologies were examined by leveraging Weiner's Cybernetics theory of feedback loops, and Speicher et al.'s expansion on the reality-virtuality continuum. These frameworks allowed us to explicitly categorize aspects of Mixed reality in the projects studied and let us tailor specific aspects of what we'd like to imbue and tease out into our own Dynamic Projection experiments. This early investigation into the confluence of PM and MR will allow us to intelligently design more interactive Projected Mixed Reality platforms in the future. The first iteration of Dynamic Projection revealed some limitations in current MR technologies, pointed out the latent potentials for the confluence of MR, and allowed us to speculate on how Dynamic Projection can help architecture be a more active participant in the Climate Movement. Our current research is expanding on those potentials and beginning to create real-world applications for use in the fields of architectural design and construction.

Acknowledgements

Thank you to the research assistants and staff at The Consortium for Research and Robotics during the Summer and Fall of 2021 in assisting with fabrication and documentation of Dynamic Projection (Rohan Saklecha, Rob Woods, Emily Gibson, and Phoebe Degroot). Thank you to Jeffery Anderson and Olivia Vien at Pratt Institute for encouraging me to produce an academic research paper after attending their class. Many thanks to Mark Parsons for supporting this research.

References

Goepel, G. (2019). Augmented Construction. ACADIA 19: UBIQUITY AND AUTONOMY, *Proceedings of the 39th Annual Conference of the Association for Computer Aided Design in Architecture (ACADIA)* (pp. 430-437).

Gwyllim, J., Andrew, W., and James, P. (2019). [BENT]: Holographic handcraft in large-scale steam-bent timber structures. ACADIA 19: UBIQUITY AND AUTONOMY *Proceedings of the 39th Annual Conference of the Association for Computer Aided Design in Architecture (ACADIA)* (pp. 438-447).

Hahm, S., (2019). Augmented Craftsmanship. ACADIA 19: UBIQUITY AND AUTONOMY, *Proceedings of the 39th Annual Conference of the Association for Computer Aided Design in Architecture (ACADIA)* (pp. 448-457).

Hrvoje, B., Wilson, A. D., and Zannier, F., (2014). Dyadic Projected Spatial Augmented Reality. *Proceedings of the 27th Annual ACM Symposium on User Interface Software and Technology.*

Jaeho, R., Naoki, H., Makoto, S., Masashi, S., and Ryuzo, O. (2006). A Game Engine Based Architectural Simulator on Multi-Projector Displays. CAADRIA 2006, *Proceedings of the 11th International Conference on Computer Aided Architectural Design Research in Asia* (pp. 613-615).

Jones, B., Rajinder S., Murdock, M., Mehra, R., Benko, H,. Wilson, A., Ofek, E., Macintyre, B., Raghuvanshi, N., and Shapira, L, (2014). RoomAlive. *Proceedings of the 27th Annual ACM Symposium on User Interface Software and Technology*.

Lasky, J., (2020) *Cybernetics.* Salem Press Encyclopedia of Science. Retrieved from https://search-ebscohostcom.ezproxy.pratt.edu/login.aspx?direct=true&db=ers&AN=87321730&site=eds-live&scope=site.

Milgram, P., Takemura, H., Utsumi, A., and Kishino, F., (1995). Augmented Reality: A class of displays on the reality-virtuality continuum. *Telemanipulator and Telepresence Technologies.*

Sangjun, A., Han, S., and Al-Hussein, M. (2019). 2D Drawing Visualization Framework for Applying Projection-Based Augmented Reality in a Panelized Construction Manufacturing Facility: Proof of Concept. *Journal of Computing in Civil Engineering,* 33 (5).

Speicher, M., Brian D. Hall, and Nebeling, M. (2019). What Is Mixed Reality. *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems.* https://doi.org/10.1145/3290605.3300767.

Teng, T., and Johnson, B. (2014) “Inspire: Integrated spatial gesture-based direct 3D modeling and display.” ACADIA 14: Design Agency, *Proceedings of the 34th Annual Conference of the Association for Computer Aided Design in Architecture (ACADIA)* (pp. 445-452).

Wiener, N. (1948). *Cybernetics: Control and Communication in the Animal and the Machine.* Wiley.