Cilt 5 Sayı 2 | Vol 5 No 2
Eylül | September
2024 | 2024
ISSN 2687-4318

J
journal of
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computational
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design

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İstanbul Teknik Üniversitesi Mimarlık Fakültesi E-Dergisi
İstanbul Technical University Faculty of Architecture E-Journal
Yılda iki kez yayınlanır. | Published two issues in one year.

Yayıncı | Publisher
İstanbul Teknik Üniversitesi Rektörlüğü | Istanbul Technical University Rectorate

İTÜ

ISSN 2687-4318

İletişim | Contact
JCoDe: Journal of Computational Design
Yayın Sekreterliği
İstanbul Teknik Üniversitesi
Mimarlık Fakültesi
Taşkışla, Taksim, 34437
İstanbul Türkiye

email: jcode@itu.edu.tr
web: jcode.itu.edu.tr

Dijital Zanaatkarlıkta Yeni Dönemler

Editörden

JCoDe'un onbirinci sayısı, hızla değişen teknolojinin etkisi altında dönüşmeye devam eden tasarımcı-tasarım nesnesi, tasarımcı-süreç ve tasarımcı-araç ilişkisini dijital zanaatkarlık bağlamında tartışmaya açmaktadır. Zanaatkarlık kavramı tarihsel olarak el ile yapılan üretim süreçlerinde ustalaşma ile ilişkilendirilmiştir. Endüstriyel dönemde tasarım ve üretim süreçlerine yeni katmanların ve araçların dahil olması, üretim sürecinin parçalara ayrılması, parçaların basitleştirilmesi, sürece makinelerin ve otomasyon sistemlerinin dahil olması ve seri üretim olanakları tasarımcının yaptığı işe yabancılaşması tartışmasını beraberinde getirmiştir. Dijital dönemde ise özellikle bilgisayar destekli tasarım ve üretimi (CAD/CAM) yaygınlaşmasının ivme kazandığı 2000'li yılların başlarında dijital zanaatkarlık kavramı farklı boyutlarıyla gündeme gelmiştir. Dijital fabrikasyon süreçlerinde ustalık ve/veya uzmanlaşma, tasarımdan-üretime bütünsel iş akışları, malzemenin biçimlendirilmesi, standardizasyon, en iyileme ve özelleştirme, algoritma okur-yazarlığı bu tartışma eksenlerinden bazılarıdır. Günümüzde ise yapay zeka araç ve yöntemlerinin çeşitlenmesi ile birlikte tasarım ve üretim süreçlerinde yeni bir dönüşüm eşiği belirmektedir ve bu bağlamda dijital zanaatkarlığın kavram, kuram ve uygulama eksenlerinde yeniden ele alınmasına ihtiyaç bulunmaktadır.

Tasarım teknolojilerinin sürekli değişmekte olduğu bir zeminde tasarımcının üretim süreci üzerindeki kontrolü ne ölçüde devam edebilir ve ustalaşma ya da uzmanlaşma mümkün müdür? Belirli bir dönem uzmanlık olarak kabul edilen bir beceri başka bir dönemde geçerliliğini yitirebilmektedir. Diğer yandan her geçen gün yeni uzmanlık alanları ortaya çıkmaktadır. Bilgisayar destekli tasarım ve üretimin yalnızca bir alt alanında uzmanlaşma, yeni yabancılaşma biçimlerine yol açabilmektedir. Tasarımcının, bir başkası tarafından geliştirilmiş olan ve çalışma mekanizması bir kapalı kutu gibi bilinmezlik taşıyan bir algoritmanın veri sağlayıcısı olmanın ötesinde içgörü ve motivasyonlara ihtiyacı bulunmaktadır. Dolayısıyla hesaplamalı tasarım ve yapay zeka çağında ustalaşma, geleneksel olarak bir ustanın yanında yaparak öğrenen çırağın sürecinden daha farklı karşılaşmalar, çabalar ve deneyimler gerektirmektedir. Richard Sennett'in zanaatkarlık tanımını genişleterek zanaatkarlığı bilişsel ve zihinsel süreçlerle birlikte bütünsel olarak ele alma önerisi, içinde bulunduğumuz dönemde zanaatkarlığın yapısökümü için ipuçları sunmaktadır.

Bu bağlamda JCoDe'un onbirinci sayısında hesaplamalı tasarım ve yapay zeka döneminde dijital zanaatkarlık ve tasarımcının değişen rolü, tasarım problemi kurma ve problem çözme ilişkisi, bağlam-duyarlı ve probleme özgü biçimlendirilen tasarım ve üretim çözümleri, tasarım nesnesinin kişiye özelleştirilebilirliği, tasarımcı- veri, tasarımcı-algoritma, tasarımcı-araç etkileşimleri, dijital zanaatkarlığın yeni tanımları ve eleştirisine odaklanan kuramsal katkılar, uygulamalar ve vaka çalışmaları tartışmaya sunulmaktadır.

Geleneksel zanaat ve malzeme bilgisinin dijital süreçler ve yöntemlerle nasıl dönüştüğüne odaklanan çalışmaların yer aldığı ilk bölümde Hülya ORAL KARAKOÇ zanaat bilgisinin parametrik hale getirilerek dijital ortamlarda korunması ve aktarılmasını ele almaktadır. Bu süreçte, örtük ve sezgisel zanaat bilgisinin nasıl kodlanabileceği ve bu bilginin dijital platformlarda nasıl paylaşılarak yeni nesil tasarım süreçlerine entegre edilebileceğini tartışmaya açarken, dijital zanaatın mimarlıkla kesişimindeki potansiyelleri ortaya koymaktadır. Zehra GÜLOĞLU, Ayşegül AKÇAY KAVAKOĞLU ve Leman Figen GÜL çalışmalarında katlanabilir kumaş kalıpların dijital zanaatkârlık ve beton döküm süreçlerinde nasıl kullanılabileceğini araştırmaktadır. Önerdikleri üç aşamalı yöntemde katlama desenlerinin seçilmesi, dijital olarak kalıp üretimi ve beton dökümü gibi süreçler yer almakta, sonuçları dijital benzetimle karşılaştırılmaktadır. Çalışma, dinamik kalıpların gelecekte mühendislik ve mimarlık gibi çeşitli alanlarda yenilikçi uygulamalar sunma potansiyeline dikkat çekmektedir. Asena Kumsal ŞEN BAYRAM, Yekta ÖZGÜVEN, Nadide Ebru YAZAR, Erincik EDGÜ ve Sebahat Sevde SAĞLAM yapay zekânın (YZ) geleneksel tasarım süreçlerine entegrasyonu üzerine odaklanarak, katılımcıların malzeme deneyimi ve YZ ile form üretimi süreçlerini incelemektedir. İnceledikleri bir çalıştay sürecinde biyopolimer malzemeler ile yapılan tasarım çalışmaları ve Midjourney gibi YZ araçlarıyla form geliştirme aşamaları detaylandırılmaktadır.

Hesaplamalı tasarımın, algoritma geliştirme ve uygulamalarının ve dijitalin zanaatinin farkjlı ölçek ve bağlamlarda ele alındığı ikinci bölümde Pınar ÇALIŞIR ADEM ve İlay Beylun ERTAN geleneksel Kurtboğaz ahşap geçme sisteminin hesaplamalı tasarım teknikleriyle nasıl yeni mimari formlar oluşturabileceğini araştırmaktadır. Birleştirici Tasarım Algoritması (BDA) kullanılarak farklı yapıların modüler ve yeniden yapılandırılabilir özellikleri incelenmekte ve geleneksel yapım yöntemlerini çağdaş mimariyle birleştirerek yeni form üretim potansiyellerini ortaya koymaktadırlar. Mahad Mohamed Elhadi IMHEMED ve Can UZUN pekiştirmeli öğrenme kullanarak etmen tabanlı modelleme ile kentsel mekânlarda yön bulma süreçlerini analiz etmektedir. Sultan Ahmet Camii ve çevresi üzerinde yapılan simülasyon çalışmaları, etmenlerin merak odaklı yön bulma davranışlarını incelemektedir. Kentsel tasarımda nöroşehircilik kavramıyla ilişkilendirilen yön bulma davranışlarını yapay zekâ aracılığıyla simüle ederek, insan merkezli şehir tasarımı için önemli girdiler sunmaktadır. Yaren ŞEKERCİ, nörobilim ile mekânsal tasarım arasındaki kesişimi ve bu alandaki son eğilimleri bibliyometrik analiz ile incelemektedir. 2003-2023 yılları arasındaki yayınları analiz ederek, insan refahını artırmayı hedefleyen biyofilik tasarım ve stres azaltma üzerine artan akademik ilgiyi vurgulamaktadır.

Dijital çağda zanaatin temsil, ortam ve etkileşim bağlamlarıyla bir arada ele alındığı üçüncü bölümde, Nurcan YILDIZOĞLU geleneksel eskiz ve dijital tasarım araçları olan CAD ve YZ destekli araçların mimari tasarım süreçlerindeki rollerini karşılaştırmaktadır. Araştırma, bu araçların yaratıcı süreçlerde nasıl birbirini tamamlayıcı nitelikte kullanıldığını analiz ederek, her iki yöntemin de tasarım süreçlerinde önemli roller oynadığını vurgulamaktadır. Zeynep Özge YALÇIN oyunlaştırma ile Yapı Bilgi Modellemesi'ni (BIM) birleştirerek tasarım süreçlerinde kullanıcı katılımını artırmayı amaçladığı araştırmasında,. BIM ortamlarında kullanılan oyunlaştırma bileşenlerinin paydaşların karar verme süreçlerine nasıl katkı sağlayabileceği değerlenlendirmektedir.

New Epochs in Digital Craftsmanship

Editorial

The eleventh issue of JCoDe explores the evolving relationships between designer-design object, designer-process, and designer-tools within digital craftsmanship, under the impact of rapidly changing technology. Historically, craftsmanship has been associated with mastery in hand-made/manual production processes. The industrial era brought new layers and tools into design and production processes, fragmenting the production process, simplifying parts, incorporating machines and automation systems, and enabling mass production. These changes have sparked discussions on the alienation of designers from their work. In the digital era, particularly with the acceleration of computer-aided design and manufacturing (CAD/CAM) in the early 2000s, the digital craftsmanship has gained prominence in various dimensions. One of the key discussion points is mastery and/or specialization in digital fabrication processes, holistic workflows from design to production, material forming, standardization, optimization, customization, and algorithm literacy. Today, with the diversification of artificial intelligence tools and methods, a new transformation threshold is emerging in design and production processes, necessitating a reevaluation of the concepts, theories, and practices of digital craftsmanship.

In a constantly evolving landscape of design technologies, to what extent can a designer maintain control over the production process, and is mastery or specialization still possible? Skills once regarded as expertise may lose their relevance over time, while new fields of expertise continue to emerge. Specialization in a single subfield of computer-aided design and manufacturing can lead to new forms of alienation. Designers need insights and motivations beyond merely being data providers for black box algorithms developed by others. Therefore, in the age of computational design and artificial intelligence, mastering craftsmanship requires different encounters, efforts, and experiences than the traditional apprentice learning alongside a master. Richard Sennett's proposal to expand the definition of craftsmanship to include cognitive and mental processes offers clues for deconstructing craftsmanship in our current era. In this context, the eleventh issue of JCoDe invites theoretical contributions, applications, and case studies focusing on digital craftsmanship and the evolving role of designers in the era of computational design and artificial intelligence. Topics of interest include the relationship between problem formulation and problem-solving in design, context-sensitive and problem-specific design and production solutions, personal customization of design objects, interactions between designer-data, designer-algorithm, designer-tools, and new definitions and critiques of digital craftsmanship.

In the first part, which focuses on how traditional craft and material knowledge are transformed through digital processes and methods, Hülya ORAL KARAKOÇ examines the parametrization of craft knowledge and its preservation and transfer in digital environments. She explores how tacit and intuitive craft knowledge can be codified and shared on digital platforms, integrating it into next-generation design processes while revealing the potential of digital craftsmanship at the intersection with architecture. Zehra GÜLOĞLU, Ayşegül AKÇAY KAVAKOĞLU, and Leman Figen GÜL investigate how foldable fabric formworks can be used in digital craftsmanship and concrete casting processes. Their proposed three-step method includes the selection of folding patterns, digital mold production, and concrete casting, with the results compared through digital simulation. The study highlights the potential of dynamic molds for innovative applications in fields such as engineering and architecture in the future. Asena Kumsal ŞEN BAYRAM, Yekta ÖZGÜVEN, Nadide Ebru YAZAR, Erincik EDGÜ, and Sebahat Sevde SAĞLAM focus on the integration of artificial intelligence (AI) into traditional design processes, examining participants' material experiences and AI-assisted form generation. They detail design studies using biopolymer materials and AI tools like Midjourney in a workshop setting.

In the second part, which addresses computational design, algorithm development, and the craft of the digital in different scales and contexts, Pınar ÇALIŞIR ADEM and İlay Beylun ERTAN explore how the traditional Kurtboğaz timber joint system can create new architectural forms using computational design techniques. Using the Aggregative Design Algorithm (ADA), they examine the modular and reconfigurable features of different structures, revealing the potential for combining traditional building methods with contemporary architecture. Mahad Mohamed Elhadi IMHEMED and Can UZUN analyze wayfinding processes in urban spaces through agent-based reinforcement learning modeling. Simulation studies around the Sultan Ahmed Mosque investigate the curiosity-driven navigation behaviors of agents, providing significant inputs for human-centered urban design by simulating wayfinding behaviors associated with neuro urbanism. Yaren ŞEKERCİ conducts a bibliometric analysis of the intersection between neuroscience and spatial design, focusing on recent trends. By analyzing publications from 2003 to 2023, she highlights the growing academic interest in biophilic design and stress reduction aimed at enhancing human well-being.

The third part combines the craft's representation, medium, and interaction aspects in the digital age. Nurcan YILDIZOĞLU compares the roles of traditional sketching and digital design tools, such as CAD and AI-assisted tools, in architectural design processes. Her research analyzes how these tools complement each other in creative processes, emphasizing both methods' significant roles play in design. Zeynep Özge YALÇIN evaluates how the integration of gamification with Building Information Modeling (BIM) can enhance user participation in design processes. She assesses how gamified components in BIM environments contribute to stakeholder decision-making processes.

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JCoDe
ournal of Computational Design

Digitalization of Craft Knowledge in Architecture: Translations and Transfers

Hülya Oral-Karakoç[1]

ORCID NO: 0000-0003-2598-8169

[1] TOBB University of Economics and Technology, Faculty of Architecture and Design, Industrial Design, Ankara, Türkiye

Ongoing discussions about the circular economy and the rise of maker culture, driven by the widespread use of computer-aided design and manufacturing technologies, have sparked increased interest in crafts among designers and architects. The craft ethos, which includes designing, making, transforming, and repairing using existing and locally available resources, fosters innovative and sustainable design practices. However, there is a recognized need for new methods to adapt the labor-intensive, manual, and iterative processes of traditional crafts for building and industrial applications. In response, efforts are underway to document and record both tangible and intangible cultural assets and to integrate craft knowledge into contemporary design processes. These efforts are transforming design by incorporating insights and techniques from traditional crafts into new design domains.

In architecture, new methods are suggested to preserve and transfer the personal and local knowledge that has developed over many years. Data sets to train generative artificial intelligence poses various challenges for intuitive processes such as crafts, where tacit knowledge is produced and transferred through the master-apprentice relationship. Thus, to implement craft knowledge to architectural design, this knowledge must be codified and formalized, that is, defined with parameters and rules. Craft processes are parameterized and digitalized through translations and transfers of knowledge such as embedded, explicit, implicit and tacit. In this emerging field of digital craft, the goal is to create a hybrid design and production process that integrates the human factors into computational design processes through a learning-by-doing approach. Therefore, all types of data, algorithms, tools and techniques acquired and simulated are within the digital craftsman's toolset along with the physical tools and techniques. The parametrization and digitalization of craft knowledge allow open-source materials to be distributed and preserved through digital platforms known as virtual guilds.

Creating new digital techniques and therefore mediums for digital craft processes is a new research area that needs to be explored by architects and designers. It has been observed that literature studies on the translations and transfer of knowledge types between digital and physical mediums in architecture are overlooked in terms of categorization of digital craft studies. This article aims to reveal the possibilities of using these knowledge cycles in the digital craft processes within architectural design. The literature review shows that digital craft studies in architecture were carried out under three categories. These are the digitalization of craft knowledge in digital heritage studies, decodifying traditional craft processes to generate digital models and hybridizing the making process by integrating the human factors into the fabrication processes. The potentials and limitations encountered in digital craft processes will be discussed as final remarks.

Keywords: Digital Craft, Digitalization, Knowledge Types, Parametrization, Tacit Knowledge.

Received: 27.06.2024
Accepted: 07.08.2024

Corresponding Author:
hkarakoc@etu.edu.tr

Oral-Karakoç, H. (2024). Digitalization of Craft Knowledge in Architecture: Translations and Transfers. *JCoDe: Journal of Computational Design,* 5(2), 163-182. https://doi.org/10.53710/jcode.1505957

Mimarlıkta Zanaat Bilgisinin Dijitalleştirilmesi: Çevrimler ve Aktarımlar

Hülya Oral-Karakoç[1]

ORCID NO: 0000-0003-2598-8169

[1] TOBB Ekonomi ve Teknoloji Üniversitesi, Mimarlık ve Tasarım Fakültesi, Endüstriyel Tasarım, Ankara, Türkiye

Bilgisayar destekli tasarım ve üretim araçlarına olan erişimin artmasıyla birlikte sonuç ürünün deneysel ve yinelemeli yapım süreçleri sonunda ortaya çıktığı zanaat üretimi, mimarların ve tasarımcıların ilgisini çekmiştir. Tasarım ve yapım ortamının potansiyelini yaratıcı şekilde kullanma olarak tanımlanan dijital zanaatta ise, sadece fiziksel değil dijital nesne, veri ve algoritmalar da dijital zanaatkarın geliştirip kollektif şekilde paylaştığı ürünler haline gelmiştir. Bu güncel zeminde, yeni dijital ortamlar kurgulamak, araştırılması gereken yeni bir alan olarak karşımıza çıkmaktadır. Mimarlığın zanaatla etkileşimde olduğu noktalarda, dijital ve fiziksel ortamlar arasındaki bilgi türlerinin çevrimi ve aktarımına ilişkin literatür çalışmalarının, ilgili çalışmaların sınıflandırılması açısından sınırlı olduğu izlenmiştir. Bu makale kapsamında, mimarlıktaki yapım süreçlerinde işlenen bilgi türleri arasındaki çevrimlerin dijital zanaat bağlamında kullanım olanaklarının ortaya konulması amaçlanmaktadır. Bu makalenin özgün katkısı olarak; dijital miras çalışmaları, geleneksel zanaat yapım süreçlerinin çözümlenmesi ve hibrit yapım ortamları geliştirilmesi mimarlığın zanaat ile temasta olduğu noktalar olarak belirlenmiş ve bu noktalar örnekler üzerinden açıklanmıştır. Makalenin sonuç bölümde ise mimarlıkta yapım bilgisinin parametrik hale getirilmesi ve dijitalleştirilmesi konusundaki potansiyeller ve kısıtlar tartışılmıştır.

Anahtar Kelimeler: Bilgi Türleri, Dijital Zanaat, Dijitalleştirme, Örtük Bilgi, Parametrelendirme

Teslim Tarihi: 27.06.2024
Kabul Tarihi: 07.08.2024

Sorumlu Yazar:
hkarakoc@etu.edu.tr

Oral-Karakoç, H. (2024) Mimarlıkta Zanaat Bilgisinin Dijitalleştirilmesi: Çevrimler ve Aktarımlar. *JCoDe: Journal of Computational Design,* 5(2), 163-182. https://doi.org/10.53710/jcode.1505957

1. GİRİŞ (INTRODUCTION)

Süregelen döngüsel ekonomi tartışmaları, bilgisayar destekli tasarım ve üretim (BDT-BDÜ) teknolojilerinin ortaya çıkardığı üretici kültürü (maker culture), tasarımcıların zanaata olan ilgisini arttırmıştır (Adamson, 2007; McCullough, 1996; Sennett, 2008). Zanaat geleneğine (craft ethos) özgü; mevcut ve yerelde bulunan kaynakları kullanarak tasarlama, yapma, dönüştürme ve onarım süreçlerinin kurgulanması yenilikçi ve sürdürülebilir tasarım süreçlerinin gerçekleşmesini sağlamaktadır. Zanaattaki el ile tekrarlı yapıma ve deneye dayanan emek-yoğun süreçlerin, etkin bir şekilde endüstriye transfer edilebilmesi için yöntem açığı olduğu Birleşik Krallık Zanaat Konseyi'nin (UK Craft Council) 2016 tarihli raporunda ortaya konulmuştur (Warburton, 2016). Türkiye'de de yaratıcı ekonominin desteklenmesi amacıyla yereldeki güçlü yönlerin ortaya çıkarılarak katma değer üretilmesine yönelik çalışmalar gerçekleştirilmeye başlamıştır (INSPIRE, 2024). Bu doğrultuda, somut ve somut olmayan kültür varlıklarının belgelenmesi ve kayıt altına alınması çalışmalarının yanı sıra (Schinagl ve Schnider, 2020; Zabulis ve diğ., 2022), zanaat bilgisinin yeni tasarım süreçlerinde kullanılmasına yönelik araştırmalar da gerçekleştirilmektedir (Chittenden, 2021; Muslimin, 2010). Bu araştırmalar günümüz tasarım ve yapım süreçlerinde üretilen ve kullanılan bilgi türlerinin dönüşümüne neden olmuştur.

Mimarlıkta uzun yıllar içerisinde kişiye ve yerele özgü olarak ortaya çıkan yapım bilgisinin (know-how) korunması ve aktarılması için yeni yöntem arayışları bulunmaktadır (Gerger ve Unal, 2022; Karakul, 2011; Kim ve diğ., 2019). Özellikle üretken yapay zekanın eğitilmesi için gerekli veri setlerinin oluşturulması, zanaat gibi örtük bilginin (tacit knowledge) üretildiği ve usta-çırak ilişkisiyle aktarıldığı sezgisel tasarım ve yapım süreçleri için çeşitli zorluklar barındırmaktadır. Bu açılardan baktığımızda, zanaat bilgisinin mimari tasarımda kullanılabilmesi için bu bilginin açığa çıkarılarak çözümlenmesi yani parametre ve kurallarla tanımlanması gerekmektedir. Dijital zanaat olarak adlandırılan bu yeni araştırma alanında, hesaplamalı tasarım yöntemleri insan faktörüyle birleştirilerek deneme-yanılma süreçlerine dayanan hibrit bir tasarım ve üretim süreci kurgulamak amaçlanmaktadır (Niedderer, 2009; Woolley, 2011). McCullough'a göre dijital zanaat çalışmalarının doğrudan malzeme ile ilişkili olması beklenmez; önemli olan belirli bir sonuç ürünü hedeflemeden mevcut ortamın tüm potansiyelini yaratıcı şekilde kullanarak tasarlamaktır (1996). Dolayısıyla, dijital ortam ve bu ortamda kullanılan ve simüle edilen her türlü veri, algoritma, araç ve teknik de dijital zanaatkarın yapım sürecinin parçaları olarak tanımlanır. Zanaat bilgisinin dijitalleştirilmesi, kitlesel olarak üretilen açık kaynaklı tasarım ve yapım (making) bilgisinin, sanal loncalar (virtual guilds) olarak adlandırılan Thingiverse, Instructables, Rhinoceros forumları gibi dijital platformlar aracılığıyla dağıtılmasını ve dolayısıyla korunmasını sağlamaktadır (Bonanni ve Parkes, 2010).

Zaman içerisinde gelişen ve değişen tasarım ve yapım süreçleri için yeni dijital teknikler ve dolayısıyla ortamlar kurgulamak araştırılması gereken yeni bir alan olarak karşımıza çıkmaktadır. Mimarlığın zanaatla etkileşimde olduğu noktalarda, dijital ve fiziksel ortamlar arasındaki bilgi türlerinin çevrimi ve aktarımına ilişkin literatür çalışmalarının, ilgili çalışmaların sınıflandırılması açısından sınırlı olduğu izlenmiştir. Bu makale kapsamında, mimarlıktaki yapım süreçlerinde işlenen bilgi türleri arasındaki çevrimlerin dijital zanaat bağlamında kullanım olanaklarının ortaya konulması amaçlanmaktadır. Bu kapsamda, dijital miras çalışmalarında zanaat bilgisinin dijitalleştirilmesi, dijital modeller oluşturmak için geleneksel zanaat süreçlerinin çözümlenmesi ve insan faktörünün fabrikasyon süreçlerine entegre edilerek yapım sürecinin hibritleştirilmesi başlıkları altında zanaat bilgisinin çevrimleri ile ortaya çıkan çalışmalar incelenecektir. Bu makalenin sonuç bölümünde ise, bu alandaki gelecek çalışmaları için dijital zanaatta karşılaşılan potansiyeller ve kısıtlar tartışılacaktır.

2. DİJİTAL ZANAAT: ZANAATIN DÖNÜŞÜMÜ (DIGITAL CRAFT: THE TRANSFORMATION OF CRAFTS)

Geleneksel anlamda zanaat, sonuç ürünün önceden tanımlı olmadığı deneme-yanılmaya dayanan yapım süreçlerini içerir. Zanaatta üretilen bilgi nesilden nesile usta-çırak ilişkisi ile ve lonca adı verilen zanaat teşkilatlanması aracılığıyla aktarılır. McCullough (1996) aynı nesnenin, belirli sayıda mekanik operasyonun el ile tekrarlı şekilde uygulanmasıyla üretildiği her türlü işin zanaat olduğunu belirtir. Pye (1968) kesinliğe dayanan makine işçiliğini, zanaat işçiliğinden ayırır ve sonuç ürünün önceden belirli olmamasından dolayı zanaat üretimini risk-işçiliği olarak tanımlar. Dolayısıyla, zanaat süreçleri, görerek öğrenilen yapım bilgisinin, belirli bir biçimi tekrar ve tekrar üretmek için kullanılmasını içerir. Beceri gelişimiyle birlikte belirli bir tecrübe kazanıldıktan sonra zanaatkar, doğaçlama ile yeni yöntem ve tasarım süreçleri kurgulayabilmektedir.

Bilgisayar destekli tasarım ve üretim araçlarının ortaya çıkışıyla zanaatın tanımı da değişime uğramıştır. Bu tanıma göre, zanaat üretiminden bahsedebilmemiz için malzeme ile doğrudan temasta bulunmak zorunlu değildir. Dijital üretimde zanaat, insanların standart teknolojik araçları öngörülemeyen süreçlere, yaratıcı şekilde uygulaması durumunu ifade eder (McCullough, 1996). Bu açıdan bakıldığında, dijital zanaatkar, fiziksel ortama göre farklı dinamikleri olan dijital ortamda da arayüzler aracılığıyla mevcut süreçlerin taklidi, yorumlanması veya dönüştürülmesi yoluyla yeni araçlar ve süreçler geliştirebilir veya mevcut tasarım ve yapım süreçlerinden tamamen bağımsız yenilikçi ürünler de ortaya çıkarabilir. Dolayısıyla, dijital zanaat farklı bilgi türlerindeki çevrimleri ve aktarımları içeren hem fiziksel hem dijital ortamda kurgulanabilecek mevcut ortamı yaratıcı şekilde kullanarak gerçekleştirilen deneysel tasarım ve üretim süreçlerini kapsamaktadır.

Tasarım ve yapım süreçlerinde üretilen, dönüştürülen veya aktarılan üç farklı bilgi türü vardır. Bunlar, açık (explicit), ima edilen (implicit) ve örtük (tacit) bilgi olarak tanımlanır (Gribbin ve diğ., 2016). Bunların yanı sıra, tasarım nesnelerinde veya mimari yapılarda donmuş halde bulunan gömülü bilgi, o nesneye veya yapıya ait tasarım ve yapım süreciyle ilgili verileri içermektedir (Thoring ve Mueller, 2012). Açık bilgi, genellikle dil aracılığıyla aktarılan ve sistematik şekilde tanımlanabilen bilgiyi ifade eder (Eraut, 2004). Tanımlar ve formüller gibi sözel veya sayısal kesinlik içeren bu bilgi türünün kullanılması ve aktarılması diğer bilgi türlerine göre oldukça hızlıdır. İma edilen bilgi ise, açık bilginin içselleştirilerek beceriye dönüşmesiyle birlikte problemlerin yenilikçi çözümünde kullanımı ile ortaya çıkmaktadır. Öte yandan örtük bilgi, bedenin kendisine kaydedilmiş olduğu için sözel olarak değil, eylemler aracılığıyla aktarılabilen bilgi türüdür. Polanyi bedensel deneyim yoluyla kazanılan bu bilginin, başlangıçta açık bir şekilde ifadesinin güç olduğundan ve ancak tarifler (recipe) yoluyla ifade edilebileceğinden bahseder. Örtük bilgi tek başına elde edilebilirken, açık bilgi ise örtük olanın anlaşılması ve tanımlanması yoluyla elde edilir (1966). Sennett'e göre, zanaatkarın ustalaşması ile yapım esnasında örtük ve açık bilgi birbiriyle sürekli etkileşim halinde kalarak yapım sürecinin analiz edilmesini ve süreçte ortaya çıkan hataların düzeltilmesini sağlar (2008). Dolayısıyla, zanaat özelinde örtük bilgi, usta-çırak ilişkisi aracılığıyla, gözlemleyerek öğrenilen ve taklit edilerek geliştirilen sezgisel bilgidir. Sezgisel olan bilginin tamamen içselleştirilerek farklı tasarım ve yapım süreçlerine aktarımı ima edilen bilgiyi oluşturur. Bu alandaki açık bilgi ise, parametre ve kurallara dayanan hesaplamalı tasarım ve üretim süreçlerinde, veri tabanlarının oluşturulmasında kullanılabilecek zanaat süreçlerinin sistematize edilmiş ve açık şekilde kodlanmış bir halini veya çevrimini ifade eder.

McCullough'a (1996) göre zanaatta el iki yönlü olarak çalışır; bunlardan ilki, elin teşhis edici (probe), ikincisi ise belirli mekanik operasyonları tekrarlı şekilde uygulayan etki edici (effector) olarak işlev görmesidir. Usta bir zanaatkar, eli ile doğrudan veya araç kullanarak belirli işlemleri malzemeye uygular. Bu sayede tasarım, malzeme ve biçim arasında bir uzlaşıya varmaya çalışır. Tüm bu süreç boyunca eller aynı zamanda üründeki kusurları analiz ederek düzeltmeler yapar. Üründeki kusurların tespiti belirli bir uzmanlık gerektirir ve bu durum ürünün kalitesiyle doğrudan ilişkilidir.

Zanaatta kullanılan araçlar da el gibi iki yönlü çalışır. Kil ile yapımdan örnek verecek olursak; oyma, şekillendirme, kesme, kazıma, yontma, fırçalama, düzleştirme için kullanılan birçok farklı araç vardır. Bunların yanı sıra, kumpaslar, açılı ölçüm cetvelleri, profil tarağı gibi ölçme araçlarından da faydalanılır. Dijital zanaatta ise, uygulayıcı ve teşhis edici olarak çalışan elin yerini çeşitli araçlar almıştır. Uygulayıcı olarak çalışan robot kol ile, farklı uç efektörleri kullanarak eklemeli, eksiltmeli, biçimlendirici fabrikasyon uygulamaları yapılabilirken bunlara ek olarak kavrayıp yerleştirme (pick-and-place) işlemi de gerçekleştirilebilir. Teşhis edici olarak ise üç boyutlu (3B) tarama teknolojileri ve sensörler kullanılmaktadır. Bu sayede, fiziksel olarak üretilen bir nesne, dijitale aktarılabilmekte ve üretime dair sapmalar ve tolerans değerleri ölçülebilmektedir. Öte yandan, geliştirilen çeşitli yazılım ve algoritmalar da mevcut araçların kullanım olanaklarının genişletilmesine ve kimi zaman beklenmedik ve beliren (emergence) sonuçlar elde edilmesine aracı oldukları için dijital zanaat ürünü olarak kabul edilmektedir. Yapma-analiz etme-yeniden yapma şeklindeki döngüsel yapım süreçlerini içeren dijital zanaatta, seri üretimden farklı olarak ortaya çıkan insan kaynaklı kusurlar veya hatalar, yaratıcı ve yenilikçi yaklaşımların geliştirilmesine yol açabilmektedir.

Yapım süreçlerindeki bu değişim, bilgisayar destekli tasarım ve üretim araçlarını kullanarak kişiselleştirilebilir ürünler geliştiren üretici (maker) adı verilen aktörün ortaya çıkmasına neden olmuştur. Sanal loncalar olarak tanımlanan dijital platformlar aracılığıyla, teorik ve uygulamalı her türlü bilgi, üreticiler arasında açık kaynaklı olarak paylaşılabilmekte, gerekli durumlarda uzman görüşü almak amacıyla kullanılabilmektedir (Sabiescu ve diğ., 2015). Ortaya çıkarılan ürünün kalite kontrolü ise, bu dağıtılmış ve merkezi olmayan çevrimiçi platformlar aracılığıyla kurulan kolektif bir akıl ile sağlanır (Bonanni ve Parkes, 2010). Ortaya çıkan kolektif bilgi birikimleri ve deneyimler bu platformlarda; metin, fotoğraf, video, algoritma, eklenti, 3B model veya veri seti halinde saklanmakta; bu dijital ürünlerin çalışan ve çalışmayan yönleri deneme yanılma yoluyla belirlenmektedir.

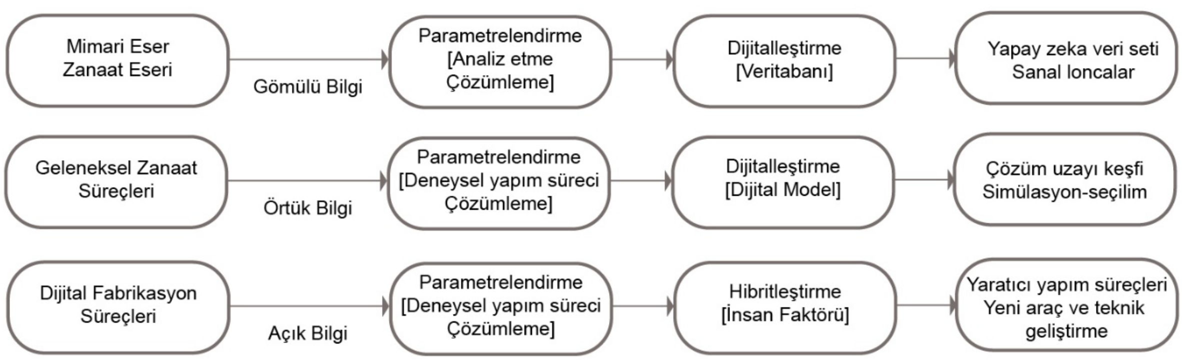
Sanal loncaların ve işbirlikçi tasarım platformlarının yaygınlaşmasıyla birlikte, sezgisel yapım süreçlerinin açık bir şekilde ifade edilmesi, örtük bilginin paylaşılmasının yeni bir yolu olarak önem kazanmıştır. Mimarlar, açık kaynaklı betikler ve yazılımlar sayesinde, el sanatlarında araçların kullanılmasına benzer şekilde dijital araçlar geliştirerek bu araçları farklı problemlere uyarlayabilmektedir (Loh ve diğ., 2016). Bu çalışmalara dayanarak, parametrik modeller, simülasyonlar ve dijital ikizler gibi ürünlerin, mimarların zihninin bir uzantısı olarak işlev görerek beceri gelişimlerine katkı sağlaması söz konusudur. Bu durumun, yaratıcı tasarım ve üretim süreçlerini hızlandıracağı açıktır.

Üreticiler arasındaki iletişimin anlaşılır ve akıcı bir şekilde sağlanabilmesi için nesnenin ölçülebilir olması ve bu sayede dijital ortamda simüle edilebilmesi için yapım sürecinin belirli kurallarla yürütülmesi gerekmektedir. El veya aletlerle gerçekleştirilen performansın parametrelendirilmesi veya parametrik hale getirilmesi (parameterization) olarak tarif edilen bu süreç, el sanatlarının dijitalleştirilmesi (digitalization) için gerekli ilk aşamayı temsil eder (Oral, 2023). Parametrik hale getirme yöntemleri, sırasıyla sıfırdan bir model geliştirmeyi veya mevcut bir geometriyi değiştirmeyi içeren yapıcı ve manipüle edici yöntemler olarak kategorize edilebilir (Agromayor ve diğ., 2021). Parametrik hale getirme, çıktının kendisini doğrudan modellemek yerine, çıktının oluşumunu etkileyen koşulları, yani dijital zanaat kapsamında yapım sürecinin kendisini, değişkenlere ve fonksiyonlara dönüştürmek olarak tanımlanabilir (Oral, 2023). Mühendislikte parametrik hale getirme çalışmaları, formun sayısallaştırılmasına odaklandığından, sezgisel karar vermeyi içeren manuel yapım süreçleri için daha kapsayıcı yöntemlere ihtiyaç duyulmaktadır. Bu nedenle, farklı bilgi türlerinin nasıl çözümleneceği, parametrik hale getirileceği ve sonrasında dijital ortama aktarımı ile ilgili süreçlerin tanımlanması gerekmektedir.

3. MİMARLIKTA ZANAAT BİLGİSİ (CRAFT KNOWLEDGE IN ARCHITECTURE)

Zanaatın mimarlıkla olan ilişkisi, yapının ölçeği gereği diğer tasarım alanlarından farklı şekilde kurulmuştur. Örneğin, seramik objeler, tamamen el ile şekillendirilebildiği halde mimari ölçekte bu durum söz konusu değildir. Dolayısıyla, mimari ölçekte yapı üretimi bireysel süreçlerden çok, işbirlikçi süreçler ile gerçekleştirilir. Geleneksel yapı ustalarının görerek öğrendiği ve yaparak geliştirdiği örtük bilgi üzerine kurulu olan ve günümüzde yerel veya geleneksel mimarlık olarak tanımlanan ekosistemde, yereldeki yapım bilgisinin ve malzeme repertuarının kullanılması söz konusudur. Yerinde yapım (in-situ) olarak tanımlanan bu deneysel süreçte malzeme, belirli araçlar ile şekillendirilerek yapı elemanları oluşturulur ve bunların bir araya getirilmesiyle de yapının kendisi inşa edilir. İyi bir yapı ustası, hesaplama yapmadan malzemeyi el ile analiz eder ve sadece örtük bilgiyi kullanarak standart olmayan strüktürler inşa edebilir (Carpo ve Kohler, 2017). Bu sebeple geleneksel mimarlıkta şantiyenin kendisi, zanaatkarın atölyesinde olduğu gibi malzeme ile birebir ilişki kurulan bir deney sahası olarak çalışmaktadır. Seri üretim sonrası dönemde şantiyenin yapısı da değişime uğramış; ön üretimli elemanların montajına dayanan ve kalitenin önceden belirlendiği bir sürece evrilmiştir. Bilgisayar destekli tasarım ve üretim araçlarının ve üretici kültürünün yaygınlaşması ile deneme yanılmaya dayanan yerinde yapım süreçleri tekrar ön plana çıkmıştır.

Şekil 1: Dijital zanaatta bilgi çevrim ve aktarım süreçleri (Yazar).

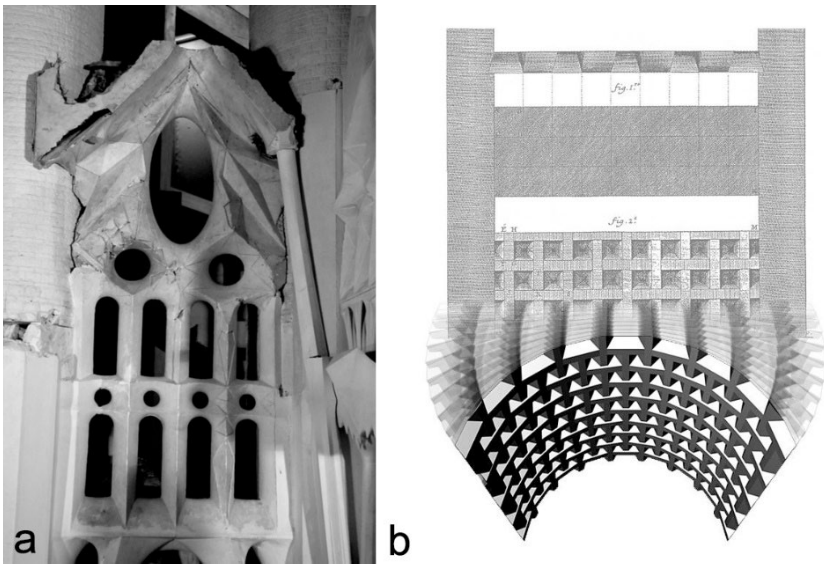


Mimarlıkta dijital zanaat çalışmalarının gerçekleştirilmesi esnasında ortaya çıkan bilgi çevrimlerine baktığımızda çözümleme, parametrik hale getirme ve dijitalleştirme süreçleriyle karşılaşmaktayız. Bu makale kapsamında, bu süreçlerdeki bilgi çevrimleri ve çevrilen bilginin farklı kullanımlara hizmet edecek şekilde genişletildiği alanlar araştırılmıştır. Gerçekleştiren literatür taraması sonucu, mimarlıkta dijital zanaat çalışmalarındaki bilgi türleri arasındaki çevrim ve aktarım süreçleri göz önüne alındığında bu çalışmaların üç kategori altında gerçekleştirildiği tespit edilmiştir (Şekil 1). Bunlardan ilki, dijital miras çalışmaları kapsamında zanaat bilgisinin açığa çıkarılması ve kaydedilmesidir. İkinci kategoride ise, geleneksel zanaat süreçlerinin çözümlenmesi ve dijital modellere dönüştürülmesi ile ilgili çalışmalar ele alınmıştır. Son olarak, bir tasarımın insan faktörünün olduğu deneysel bir süreçle, fabrikasyon araçlarını kullanarak hibrit bir ortamda üretilmesini içeren çalışmalar incelenmiştir. Zanaat bilgisinin çevrimleri ile kullanım olanaklarının genişletilmesi sonucu, mimarlıkta birçok farklı akademik çalışma gerçekleştirilmektedir.

3.1 Dijital Miras Çalışmaları Kapsamında Dijital Zanaat (Digital Craft in Digital Heritage Studies)

Dijital miras çalışmalarında bilgi türleri arasındaki çevrimler, başka bir çağa, mimara, ustalığa ve yapım türüne ait mimari eserlerin belgelenmesi, eksik parçalarının tamamlanması, strüktürel veya yapısal açıdan güçlendirilmesi gibi amaçlarla gerçekleştirilir. Bu çevrim süreci; ustanın, malzemenin, kullanılan araçların ve tekniklerin veya yapının kendisinde depolanmış gömülü bilginin açığa çıkarılmasıdır. Özellikle arkeoloji çalışmalarında da kullanılan bu bilgi türü ile buluntu nesnelerin ne şekilde üretildiği ve buna bağlı olarak hangi döneme ait olduğu tespit edilebilmektedir. Mimarlıkta ise tarihi yapılar üzerinden biçimsel bir analiz gerçekleştirilerek parametrelere ve kurallara bağlı bir biçim kütüphanesi oluşturulabilir. Bu şekilde, yapının veya yapı bileşenlerinin kendisinde bulunan donmuş bilgi açığa çıkarılarak çeşitli biçimsel, boyutsal ve tekniğe ait parametreleri içeren bir veri tabanı oluşturulabilir. Yapay zekanın eğitilmesi için kullanılabilen bu veri tabanından farklı coğrafyalardaki zanaatkarlara ve müzelerde ise ziyaretçilere bilgi aktarılmasında da faydalanılabilir (Şekil 1).

Gaudi'nin Sagrada Familia yapısında bulunan gül pencerenin, önceden üretilmiş fiziksel modellerinden yola çıkarak geliştirilen parametrik tasarım yazılımı ile üretilmesi bu alandaki çalışmaların ilk örneklerinden biri olarak kabul edilir (Burry ve diğ., 2001) **(Şekil 2a)**. Farklı bir döneme ve mimara ait bu yapının tamamlanmamış bölümleriyle ilgili inşa süreci mimarlar ve taş ustaları arasındaki iş birliği ile gerçekleştirilmektedir. Stereotomi adı verilen, doğal taşın aletler yardımıyla uygulanan ardışık eksiltme operasyonlarıyla şekillendirilmesine dayanan bu alanda farklı dijital zanaat çalışmaları gerçekleştirilmiştir. Abeille ve Truchet örüntülerinin kullanıldığı tonozların dijital araçlarla yeniden üretildiği dijital stereotomi çalışmaları, taş işçiliğinin yeniden canlandırılması ve dijital araçlarla üretilmesine örnek olarak verilebilir (Fallacara, 2006; Fallacara ve diğ., 2019) **(Şekil 2b)**.



Şekil 2: Sagrada Familia gül pencere detayı (a) (Burry ve diğ., 2001), Joseph Abeilles'in kesme taştan beşik tonozunun dönüşümü (b) (Fallacara, 2006).

Literatürde, geleneksel yapılarda bulunan yapı bileşenlerinin analizine ve üretilmesine dayanan birçok çalışma bulunmaktadır. Selçuklu dönemine ait mezarda bulunan on iki yüzlü sütun başlığındaki mozaik bezemenin geometrik analizi (Özgan ve Özkar, 2017), mukarnasın geometrik analizi ve parametrik tasarım araçlarıyla yeniden üretimi (Alaçam ve diğ., 2017) ile Anadolu'daki tarihi bir taş oymanın dijitalleştirilmesi ve fabrikasyon araçlarıyla üretilmesi (Hamzaoglu ve Özkar, 2023) bu çalışmalara örnek olarak verilebilir. Öte yandan, tarihi veya yapılı çevrenin dijitalleştirilmesi; üretilen dijital modellin farklı dijital platformlarda (arttırılmış ve sanal gerçeklik uygulamalarında) ve dijital oyunlarda kullanılmasını da sağlamaktadır (Porreca ve diğ., 2020; Sancak ve diğ., 2023). Bahsi geçen çalışmaların ortak özelliği, başka bir çağa ait yapısal bileşenlerin incelenerek geometrik ve matematiksel olarak çözümlenmesi ile parametrik hale getirilmesi ve dijitalleştirilmesi süreçlerini içermeleridir. Bu süreci takiben biçimsel çeşitliliğin arttırılması, mevcut üretim biçimine bağlı çözüm uzayının araştırılması, istenen strüktürel veya çevresel performansa uygun elemanın seçilmesi, geliştirilen dijital platformların oyunlaştırma ve eğitim süreçleri için kullanılması mümkün hale gelmektedir.

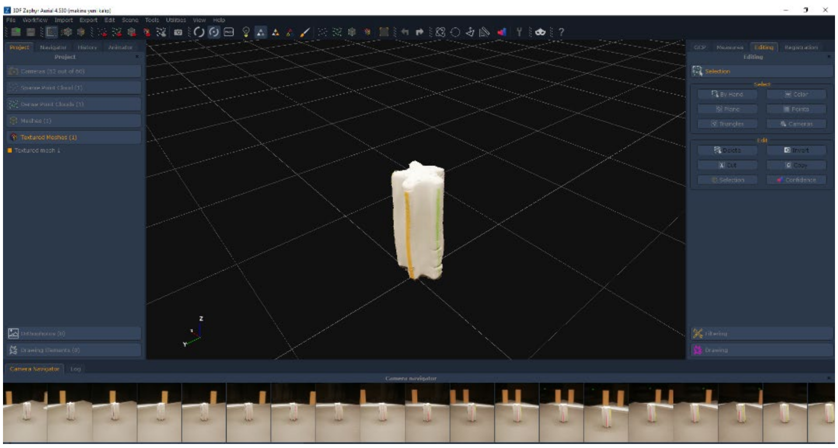
3.2 Geleneksel Zanaat Süreçlerinin Çözümlenmesi Kapsamında Dijital Zanaat (Digital Craft for Analyzing Traditional Craft Processes)

Zanaat süreçlerinin dijital ortama çevriminde kullanılan diğer bilgi türü, yapı ustasının yapım esnasında malzeme ve araçlarla kurduğu bedensel ilişki ile tanımlanan örtük bilgidir. Bu bilgi usta-çırak ilişkisiyle aktarılan dolayısıyla, belirli bir ortamdaki sözlü veya sözsüz iletişim öğelerini içerir. Farklı malzemelerin işlenmesi, farklı araçların ve tekniklerin kullanımını gerektirdiğinden ortamın belirleyici olduğu bir olanaklılık (affordance) söz konusudur. Örneğin, stereotomide yontma araçları ile ardışık eksiltme operasyonlarının uygulanması sonucu istenilen biçime ulaşılır. Kil ise katı formda el, torna veya kil biçimlendirme araçlarıyla şekillendirilebilirken slip adı verilen sıvı formunda kalıba dökülerek istenilen biçime getirilmektedir. Bu bilgi türünün dijitalleştirilebilmesi için mevcut yapı elemanının ne şekilde üretildiğinin belirli parametrelere ve kurallara dayalı olarak çözümlenmesi gereklidir.

Biçim ve yapım grameri oluşturma gibi kurala dayalı yöntemlerle, mevcut tasarım süreçleri çözümlenebilmekte (Colakoğlu, 2005; Stiny ve Mitchell, 1978) ve mevcut tasarımlardan türetilen bir kural seti aracılığıyla yeni stiller oluşturulabilmektedir (Duarte, 2005; Stiny, 1980). Yapım grameri çalışmaları, tasarımların bir dizi komut aracılığıyla hayata geçirilmesine odaklanmıştır (Stiny, 2015). Bu bağlamda, malzemeyi açıkça işleyerek ortaya çıkan biçimleri keşfetmeye (Gürsoy ve Özkar, 2015; Knight ve diğ., 2008; MacLachlan ve Jowers, 2016), malzeme ve bağlantı detayına ilişkin yapı bileşenlerinin montaj sürecini sistematize etmeye dayanan (Knight ve diğ., 2008; Sass, 2006, 2008) çeşitli uygulamalı yapım süreçleri gerçekleştirilmiştir.

Şekil 3: MoCap ile beden hareketlerinin dijitalleştirilmesi (Zabulis ve diğ., 2022)

Zanaatkarlarla röportajlar gerçekleştirilerek ve yapım süreçleri video veya fotoğraf yoluyla belgelenerek bu örtük bilgi kaydedilebilir (Kendir B., 2015). Aynı zamanda, MoCap gibi beden hareketlerini dijitalleştiren araçlar kullanılarak zanaatkarın el ve vücut hareketleri kayıt alına alınırken fotogrametri ile mevcut yapısal bileşenler dijital ortama aktarılabilir (Zabulis ve diğ., 2022) **(Şekil 3)**. Örneğin, kil ve ekstrüzyon aracı ile üretilen zanaat ürününün, 360^{o} etrafında dönülerek çekilmiş fotoğraflarının fotogrametri yazılımında birleştirilmesiyle dijital bir temsili veya ikizi oluşturulabilir (Oral, 2023) **(Şekil 4)**.



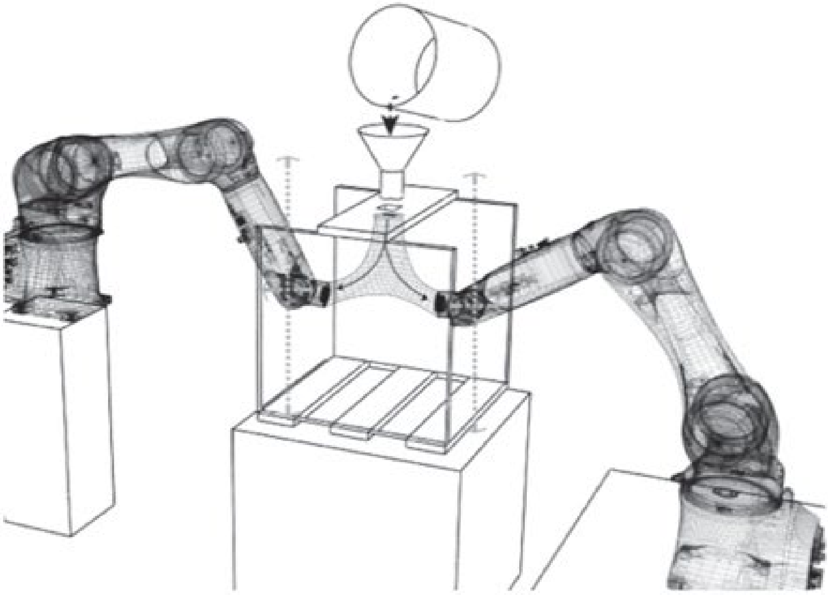
Şekil 4: Fiziksel ürünün 360^{o} fotoğraflarıyla oluşturulmuş dijital temsili (Yazar)

Farklı şekillerde toplanıp kaydedilen bu yapım bilgisi, çırakların yetiştirilmesi için geliştirilen arttırılmış ve sanal gerçeklik ortamlarında kullanılabilirken, aynı zamanda, robot kolların programlanmasında faydalanılan alt yapıyı sağlayabilmektedir. Robotik fabrikasyonda yeni uç efektörlerin geliştirilmesi ve bu yeni araçlara dayanan yeni biçim ve yapım süreçlerinin kurgulanmasına dair birçok çalışma bulunmaktadır. Bunlar; geleneksel tuğla duvar inşa sürecinin parametrik hale getirilerek standart olmayan yüzeylerin örülmesi (Gramazio ve diğ., 2014) ve 3B kil baskı teknikleriyle standart olmayan dolgulara sahip tuğlalar geliştirilmesi (Sangiorgio ve diğ., 2022) gibi çalışmalardır. Bu çalışmaların ortak özelliği, mimar olarak geleneksel yapım süreçlerine büyüteç tutmak ve bu deneysel ortamın potansiyellerini keşfedecek şekilde yapım sürecinin içerisinde kimi zaman taş ustaları gibi farklı aktörlerle birlikte doğrudan yer alabilmektir.

3.3 Hibrit Yapım Süreçleri Kurgulanması Kapsamında Dijital Zanaat (Digital Craft in Hybrid Making Processes)

Seri üretimin ortaya çıkışına kadar tam bir deney sahası olarak görev yapan şantiyenin ve dolayısıyla malzeme ile doğrudan ilişki kurarak yenilikçi yapılar inşa eden ustaların yapım süreçleri içerisine tekrar dahil edilmesi yönündeki çalışmalar, kısmen otomatize edilmiş bina yapım süreçlerinin yeniden ele alınmasına neden olmuştur. Öte yandan, bilgisayar destekli tasarım ve üretim araçlarının yaygınlaşmasıyla birlikte dosyadan fabrikaya (file-to-factory) olarak isimlendirilen yapım süreçleri sorgulanmaya başlanmıştır. Dijital fabrikasyon araçlarının pahalı, tek fonksiyonlu, tasarımcının doğrudan müdahalesine kapalı ve dolayısıyla özelleştirilmelerinin güç olması (Oxman, 2007; Peek ve Moyer, 2017) ve dijital fabrikasyon araçlarının kullanımının belirli bir dijital okuryazarlık gerektirmesi (Katterfeldt, 2014) gibi sebeplerle dijital fabrikasyon araçları ve insanın birlikteliğinden oluşan bir hibrit zemin arayışı ortaya çıkmıştır. Bu bağlamda hem şantiye hem de fabrikasyon laboratuvarları, yeni biçimlerin ve süreçlerin deneme-yanılma yoluyla keşfedildiği bir deney sahası olarak kullanılmaya başlanmıştır. Buna ek olarak, tasarımcının yapım süreçlerinin doğrudan içerisinde yer alarak yaparak öğrenmesi (learning-by-doing) de bu alanın gelişmesinde önemli rol oynamıştır. Bu sayede, yeni bilgilerin aktarımı ve çevrimi sağlanmış ve bu bilgiler farklı ortamlarda test edilebilmiştir.

Bu bilgi çevrim sürecinde, fiziksel yapım süreçlerini destekleyen dijital araçların kullanımıyla uzman olmayan üreticiler dahi yeni araçlar geliştirebilmektedir (Jorgensen, 2019; McCullough, 1996; Pye, 1968). Esnek ve yeniden yapılandırılabilir olarak tanımlanan araçlar, yapım süreçlerini hibrit hale getirmek amacıyla mevcut üretim süreçlerinin yorumlanması yoluyla geliştirilmektedirler. Bu alandaki çalışmalar, tek bir hareketli kalıp sistemiyle farklı biçimlerin üretilmesi (Bechthold, 2016; Khabazi ve Budig, 2016), kil ekstrüzyon aracı gibi manuel zanaat araçlarının hareketli parçalarla özelleştirilmesi (Oral, 2023) veya robotik kollar aracılığıyla esnek kumaş kalıpların döküm imalatında kullanılmak üzere numerik kontrollerinin sağlanması (Culver ve diğ., 2016) konularına odaklanmaktadırlar **(Şekil 5)**.



Şekil 5: Robotik döküm kurulumu (Culver ve diğ., 2016)

Bu alandaki diğer çalışmalar, yeni araçların ve tekniklerin potansiyelini keşfederek standart olmayan biçimlerin üretilmesinin yanı sıra, insana ve yapıma özgü hata oranlarının belirlenerek dijital modellere geribildirim sağlamaya yöneliktir. Bunlar, insanın yapım esnasındaki hata değerlerinin tasarım sürecine entegre edildiği 3B kalem ile üretilen enstalasyon (Clement ve diğ., 2018) ile poliüretan köpük kullanılarak inşa edilen strüktür (Lopez ve diğ., 2016) çalışmalarıdır. Deneysel yapım sürecinde ortaya çıkan beklenmedik durumlar hedeflenen biçimden sapılmasına neden olarak yaratıcı süreçleri tetiklerken öte yandan, bu sapma oranlarının tespiti, dijital veya parametrik modele geribildirim sağlayabilmektedir.

4. SONUÇ (CONCLUSION)

Bu makale kapsamında, mimarlıkta ve tasarımın diğer alanlarında zanaat süreçlerinin çözümlenmesi, parametrik hale getirilmesi ve dijitalleştirilmesi çalışmalarında kullanılmak üzere, bu süreçlerde üretilen bilgi türleri ve bunlar arasındaki çevrimlere dayanarak literatürdeki çalışmalar analiz edilmiştir. Bu doğrultuda, yapılardaki ve yapısal bileşenlerdeki gömülü bilgi, yapım esnasında ortaya çıkan örtük bilgi ve dijital fabrikasyon süreçlerinde parametrelere ve kurallara dayanan açık bilgi, dijital zanaat çalışmalarında çevrimler yoluyla kullanılan bilgi türleri olarak karşımıza çıkmaktadır. Bu bilgi türleri arasındaki çevrimler döngüsel, doğrusal ve hibrit şekilde gerçekleşerek zanaata ait bilginin farklı tasarım ve yapım alanlarına aktarılmaları yoluyla kullanım olanaklarının genişlemesine katkı sağlamaktadır. Bu nedenle, mevcut eserlerin yapım yöntemlerinin analizi ve çözümlenmesi hem yeni süreçlerin geliştirilmesini hem de mevcut yöntemlerin kaydedilmesini ve saklanmasını sağlamaktadır. Dijital zanaat çalışmaları, farklı bilgi türlerindeki çevrimleri ve aktarımları içeren ve farklı tasarım ortamlarını (dijital, fiziksel veya hibrit) yaratıcı şekilde kullanarak gerçekleştirilen deneysel tasarım ve üretim süreçlerini kapsamaktadır.

Dijital zanaatkar olarak mimar, bilgisayar destekli tasarım ve üretim araçları sayesinde belirli bir uzmanlığa sahip zanaatkarın yıllar içerisinde geliştirdiği yapım bilgisini simüle etme, yorumlama ve uygulama imkanına kavuşmuştur. Bu sayede, malzeme ve araçlarla doğrudan etkileşim içerisine giren mimar, el ile detaylandırılması ustalık ve maliyet gerektiren üretimleri dahi gerçekleştirebilmektedir. Bu açıdan baktığımızda mimarın güncel rolünün, bazen bir tuğlanın tasarımından başlayabilen, alternatif çözümlerin dijital veya fiziksel ortamda deneme yanılma yoluyla keşfedildiği süreçlerin içerisinde bulunmak olduğunu söyleyebiliriz. Ancak, fabrikasyon araçlarıyla üretilen ürünlerin son rötuşlarının hala el ile yapılması, mimarların zanaatkarlarla olan ortak çalışmalara ihtiyaç duyduğunun da önemli bir göstergesidir. Bu tür iş birlikçi çalışmalarda ise, tasarım ve üretim süreçlerine ait bilgi türleri arasındaki çevrimlerin ve aktarımların iyi bir şekilde analiz edilmesi, farklı aktörler arasında doğru iletişim kanallarının kurulmasını sağlamaktadır.

Dijital zanaat alanındaki çalışmaların artışına rağmen mimarlıkta zanaat bilgisinin dijitalleştirilmesine yönelik birçok endişenin varlığı söz konusudur. Genel olarak bu endişeler; zanaat bilgisinin toplanması, kaydedilmesi ve açık kaynaklı hale getirilmesi ile ilgilidir. Yerel veya kişisel yapım süreçlerine dair bilginin toplanması ve kaydedilmesi zanaatkara veya ustaya özgü yapım bilgisinin kopyalanmasının önünü açmaktadır. Bu durum, telif haklarıyla ilgili birtakım sorunlara sebep olabilmektedir. Zanaatta üretilen bilginin ortama ve kişiye bağlı olması, mühendislikteki parametrik hale getirme ve dijitalleştirme çalışmalarından farklı olarak genellenebilir bir sayısal modelin oluşturulmasını zorlaştırmaktadır. Deneysel süreçlerin kurgulanmasına ve uygulanmasına harcanan zaman, maliyet ve emek göz önüne alındığında dijital zanaat çalışmaları, hızlı çözüm gerektiren problem alanları için tercih edilmeyebilmektedir. Bu nedenle harcanan çaba ve maliyet ölçümünde dengeyi yakalamak dijital zanaatkarın tecrübesiyle doğru orantılıdır.

Tüm bu endişelere rağmen, halihazırda 'MadeEu', 'INSPIRE', 'Digitalization and innovation in skilled crafts and trades' gibi projeler kapsamında geleneksel zanaat çalışmalarının kayıt altına alınması, dijital zanaat projelerinin geliştirilmesi ve zanaatkarların yetiştirilmesi için Türkiye'de ve dünyada birçok farklı proje yürütülmektedir (*INSPIRE*, 2024; *Made@Eu*, n.d.; *Projects - IAGF*, n.d.). Bu projeler, dijital zanaat yöntemlerinin tasarımın tüm alanlarında uygulanabilmesi için büyük potansiyel taşımaktadır. Dijitalleşme ve bunun sebep olduğu bilgi çevrimlerinin, gelecek sektörel ve akademik çalışmalar açısından da farklı paradigma kaymalarına sebep olabileceği öngörülebilir. Bu açıdan bakıldığında, mimarlıkta zanaat bilgisinin dijitalleştirilmesi; Mimarlık, Mühendislik ve İnşaat (AEC) endüstrisinin aşamalı ve anlık bir biçimde geliştirilmesinde öncül bir yaklaşım olarak değerlendirilme potansiyeline sahiptir. Mimarlık alanında da bu tür çalışmaların geliştirilmesi için gerekli adımların atılması; yerel ve sürdürülebilir mimari yaklaşımların geliştirilmesi ve tekrar yaygınlaştırılması açısından büyük önem taşımaktadır.

Çıkar Çatışması Beyanı (Conflict of Interest Statement)

Yazar, bu çalışmada sonuçları veya yorumları etkileyebilecek herhangi bir maddi veya diğer asli çıkar çatışması olmadığını beyan eder.

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An Experimental Approach to Use Foldable Fabric-Formwork in Digital Craftsmanship

Zehra Güloğlu[1], Ayşegül Akçay Kavakoğlu[2], Leman Figen Gül[3]

ORCID NO: 0009-0008-2313-8789[1], 0000-0002-5910-3560[2], 0000-0001-9374-4620[3]

[1] Istanbul Technical University, Graduate School, Department of Informatics, Architectural Design Computing, Istanbul, Turkey
[2] Istanbul Technical University, Faculty of Architecture, Department of Landscape Architecture, Istanbul, Turkey
[3] Istanbul Technical University, Faculty of Architecture, Department of Architecture, Istanbul, Turkey

Since the 1950s, various studies on fabric-formwork systems have been developed. However, since the 2000s, with the rise of computational methods, the relationship between fabric-formwork and craft has been explored from specific perspectives, leaving gaps in the field concerning the reusability of molds and the production of form variations. This study aims to explore the potential of integrating traditional and digital methods by examining the relationship between foldable fabric-formwork systems and concrete within the framework of digital craftsmanship in a form-specific manner. The methodology of this study comprises three stages, which are: i) the selection of folding pattern, ii) the production of foldable formwork through digital craftsmanship, and iii) the casting of concrete into fabric molds. These stages involve a feedback loop between the computational and analog modelling approaches. To investigate the potential of different form alternatives, a series of physical experiments were conducted. The experiments conducted revealed that the resulting forms were significantly influenced by the material mixture, the type and properties of the fabric, and the mold structure. Consequently, to ascertain the veracity of the physical products generated, simulations were initially conducted in a computational-design environment following the pouring concrete. Thereafter, the physical products were 3D-scanned with a comparison subsequently made. The findings indicate that the utilization of dynamic molds holds significant potential for future applications in various fields including engineering, architecture, and art.

Received: 08.07.2024
Accepted: 16.09.2024

Corresponding Author:
guloglu23@itu.edu.tr

Güloğlu, Z., Akçay Kavakoğlu, A., & Gül, L. F. (2024). *An Experimental Approach to Use Foldable Fabric-Formwork in Digital Craftsmanship. JCoDe: Journal of Computational Design*, 5(2), 183-209. https://doi.org/10.53710/jcode.1512878

Keywords: Digital Craftsmanship, Fabric-Formwork, Fabrigami, Folding.

Dijital Zanaatkarlıkta Katlanabilir Kumaş Kalıp Kullanımına Yönelik Deneysel Bir Yaklaşım

Zehra Güloğlu[1], Ayşegül Akçay Kavakoğlu[2], Leman Figen Gül[3]

ORCID NO: 0009-0008-2313-8789[1], 0000-0002-5910-3560[2], 0000-0001-9374-4620[3]

[1] İstanbul Teknik Üniversitesi, Lisansüstü Eğitim Enstitüsü, Bilişim Anabilim Dalı, Mimari Tasarımda Bilişim, İstanbul, Türkiye
[2] İstanbul Teknik Üniversitesi, Mimarlık Fakültesi, Peyzaj Mimarlığı Bölümü, İstanbul, Türkiye
[3] İstanbul Teknik Üniversitesi, Mimarlık Fakültesi, Mimarlık Bölümü, İstanbul, Türkiye

1950'lerden bu yana kumaş kalıp sistemleri üzerine çeşitli çalışmalar geliştirilmiştir. Ancak, 2000'lerden itibaren hesaplamalı yöntemlerin yükselişiyle birlikte, kumaş kalıp sistemleri ve zanaat arasındaki ilişki belirli perspektiflerden incelenmeye başlanmış ve kalıpların yeniden kullanılabilirliği ile form varyasyonlarının üretimi konusunda alanda boşluklar bırakılmıştır. Bu çalışma, katlanabilir kumaş kalıp sistemleri ve beton arasındaki ilişkiyi, dijital zanaatkârlık çerçevesinde, forma özgü bir şekilde inceleyerek, geleneksel ve dijital yöntemleri birleştirmenin potansiyelini keşfetmeyi amaçlamaktadır. Bu çalışma üç aşamadan oluşur: i) katlama deseninin seçilmesi, ii) dijital zanaatkarlık aracılığıyla katlanabilir kalıp üretimi, iii) betonun kumaş kalıplara dökülmesi. Farklı form alternatiflerini görebilmek için çeşitli fiziksel deneyler yapılmıştır. Bu deneylerin ışığı altında, ortaya çıkan formlar üzerinde malzeme karışımı, kumaş cinsi ve özelliği, ve kalıp strüktürünün etkili olduğu görülmüştür. Sonuç olarak, elde edilen fiziksel ürünlerin dijital ortamla doğruluğunu test etmek için ilk önce hesaplamalı tasarım ortamında beton döküldükten sonraki simülasyonu yapılmıştır. Daha sonra 3B sayısal-tarama yöntemleri kullanılarak fiziksel ürünler taratılmış ve bir karşılaştırma yapılmıştır. Elde edilen bulgular, gelecekte dinamik kalıpların kullanımının mühendislik, mimarlık ve sanat gibi birçok alanda kullanılabilecek yeni potansiyeller taşıdığını göstermektedir.

Anahtar Kelimeler: Dijital Zanaatkarlık, Fabrigami, Katlama, Kumaş Kalıp.

Teslim Tarihi: 08.07.2024
Kabul Tarihi: 16.09.2024

Sorumlu Yazar:
guloglu23@itu.edu.tr

Güloğlu, Z., Akçay Kavakoğlu, A., & Gül, L. F. (2024). *Dijital Zanaatkarlıkta Katlanabilir Kumaş Kalıp Kullanımına Yönelik Deneysel Bir Yaklaşım. JCoDe: Journal of Computational Design,* 5(2), 183-209. https://doi.org/10.53710/jcode.1512878

1. INTRODUCTION

The use of flexible fabric formwork, which has significantly influenced the existence and production methods of concrete in architecture, dates back to the mid-20th century. This method emerged during World War II, particularly at a time when construction materials were scarce, offering several advantages such as resisting the hydrostatic pressure exerted by concrete, filtering excess water, and increasing the strength of the concrete (Orr et al., 2011). In 1941, the Irish engineer James Waller developed one of the first notable applications of this technique—the Ctesiphon roof system. This system utilized a combination of jute fabric and concrete to create wide-span and thin structures. In the 1950s, Felix Candela further advanced this method, leading to significant projects in Mexico. During the 1970s and 1980s, Spanish architect Miquel Fisac explored the potential of concrete using flexible formwork, producing highly detailed surfaces and complex geometric forms. He used these formworks to produce cladding panels with varied textures and forms by controlling their deformation during casting (Pedreschi, 2013).

At the beginning of the 2000s, interest in this technique increased further with the establishment of the research center CAST by Mark West, focusing on how flexible formwork can be used innovatively and efficiently in architectural design. Since then, technological advancements have led to the development of entirely new methods that integrate digital design and craftsmanship. Numerous concrete elements have been cast using fabric formwork, with the continuous development of precise tools through both digital and analog methods remaining a key area of research (Veenendaal & Block, 2012; Hawkins et al., 2016; West, 2016). Initially, in 2009, Andrew Kudless, founder of MATSYS Design Studio, created the installation titled "P_Wall" at the San Francisco Museum of Modern Art. This project utilized flexible fabric formwork and computational methods to create a dynamic simulation environment through form-finding. However, the physical formwork used remained static (Huang & Belton, 2014).

In subsequent years, Meibodi and Tessmann (2014) differentiated their approach by using CNC machining and handcrafting techniques to cast concrete into an MDF formwork that only moved along the diagonal axis, producing a hyperbolic paraboloid geometric form. In the same year, Schmitz (2014) introduced methods for using fabric formwork in the construction industry, including tensioned fabric formworks and air-inflated fabric formworks. These innovative methods offer advantages such as cost-effectiveness, lightweight, portability, design flexibility, and waste reduction. More recently, Szabo et al. (2019) employed the Smart Dynamic Casting (SDC) method with robotic fabrication to produce thin folded concrete units using a rigid and fixed formwork **(Table 1).** This study produced concrete units approximately 1.50 meters in size using digital casting; however, collapse occurred after reaching a certain height. Among the most innovative approaches in concrete production is the work by Lloret-Fritschi et al. (2023), who first introduced a two-state dynamic mold made from waxed paper for lightweight mold production. Although they demonstrated successful concrete production with these paper molds, their approach required the peeling of the mold for concrete removal, resulting in a single-use mold.

The examination of these concrete formwork systems has identified two key issues. First, there is concern regarding the durability and longevity of the fabric materials, which is particularly concerning in the case of single-use materials that may pose environmental risks. Second, there are the variations that can occur during the assembly, tensioning, and support of the fabric. These variations can lead to inconsistencies in the formwork geometry, increasing the risk of not achieving the desired shape after the concrete is cast (Liebringshausen et al., 2023). To address these challenges, the controlled assembly and use of fabric as formwork presents a more sustainable, lightweight, globally accessible, and reusable alternative compared to traditional formwork systems (Lo & Wang, 2024).

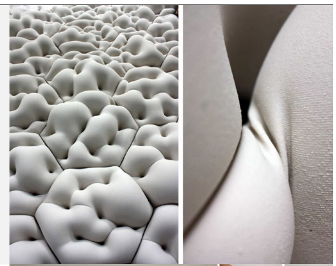
Order/ Researchers	Geometric Form	Casting and Molding Material	Folding or Hinging in Formwork	Kinetic Mechanism	Design & Manufacturing Method	Impact & Performance	Images of Physical Prototypes
1. Kudless (2009), founder of MATSYS Design Studio	-Hexagon modules	-Pouring plaster onto nylon fabric-formwork	-Fixed wooden dowels	-Fixed fabric-formwork	-Computational Form-Finding -Handcrafting (Nylon fabric stretched over wooden dowels)	-Rich configuration through varying distribution of dowels within modules -Formation of uniform organic forms	
2. Meibodi & Tessmann (2014)	-Hyperbolic paraboloid	-Pouring gypsum onto paper mold -Pouring gypsum onto plastic mold -Pouring concrete onto plastic mold -Pouring concrete onto MDF mold	- Folding with paper - Hinging in MDF mold (with textile-reinforced tape)	-Dynamic formwork (only movement on diagonal axis)	-Computational design and simulation -Handcrafting -CNC machining	-Reusable formwork -Easier form explorations with paper molds -Better gypsum performance in the plastic mold -Better concrete performance in the MDF mold	
3. Szabo et al. (2019)	-Thin folded geometry with a straight curve -Thin folded geometry with a bezier-curved -Thin folded geometry with a sine-curved	Pouring concrete into foil formwork	- Fixed folded foil formwork	-Rigid folded formwork	-Computational design -Robotic fabrication production using Smart Dynamic Casting (SDC) method	-Reusable formwork -Uneven distribution of the material within the mold -Collapse occurring at a certain height in the Bezier-curved prototype -Cracking in the Sine-curved prototype	
4. Lloret-Fritschi et al. (2023)	-Thin folded geometry with curved creases -Folded geometry with nested creases	-Pouring concrete into 2mm museum board formwork -Pouring concrete into 0.4 mm wax paper formwork	-Folding with paper	-Dynamic formwork (a bistable structure)	-Computational design -Robotic fabrication production using Admixture Controlled Digital Casting (ACDC) method -CNC machining	-Single-use formwork -Smooth surface finish with museum board mold -A relatively smooth surface finish with air pockets and minor imperfections with waxed paper mold	
5. Authors (2024)	-OctaBowl	-Pouring white concrete into kitchen cloth fabric formwork -Pouring white concrete into white-flannel fabric formwork	-Hinging and folding in fabric formwork	-Dynamic formwork (Multiple degrees of freedom with designed joints)	-Computational design and simulation -Handcrafting -Digital fabrication with 3D printer	-Reusable formwork -Relatively smooth surface finish except for the trace left by the mould frame -Formation of catenary curve shapes by concrete self-forming using fabric	

Table 1: A comparison between the existing concrete formworks and the dynamic formwork produced in this research.

Various techniques have been developed to effectively utilize fabric formwork during the form-finding stages. As commonly seen in existing studies, the fabric is typically fixed in place. However, Akçay Kavakoğlu (2020) proposed a novel approach by applying the fabrigami technique to fabric, enabling the production of dynamic formwork.

Since this technique draws inspiration from the fundamental principles of origami, it is essential to first understand the concept of origami itself. Origami is known as a generative technique used to create complex geometric forms by folding rigid surfaces according to rule-based relationships (Song et al., 2024), and originating from Japanese, the term is derived from “oru” (折る-*to fold*) and “kami” (紙-*paper*). This characteristic has inspired various disciplines and contributed to the development of diverse structures. One such technique inspired by origami is fabrigami, which is known as the art of folding fabric (Ahmed et al., 2020). To fold the fabric into the desired pattern, stitching lines are created on it, and folds are made along those lines (Wang et al., 2022). In architecture, Samira Boon and her Studio in Amsterdam explore innovative uses of fabric, combining origami techniques with digital manufacturing to create dynamic, interactive spaces (Boon, 2024). Some of the studio's projects are illustrated below **(Figure 1)**.

All of these processes require both analog and digital craftsmanship in terms of the level of detail and the need for artistic skills in fabric formwork. According to McCullough (1998), digital craftsmanship allows artisans to integrate traditional craft techniques with digital technologies, enhancing their ability to solve complex challenges and develop innovative solutions. This integration enables artisans to effectively use digital tools to overcome intricate problems and create novel solutions (Kilian, 2007). This study aims to explore the potential of combining traditional and digital methods, akin to McCullough's concept of digital craftsmanship, by a dynamic fabric mold is produced through a different crease-pattern, and the strengths and weaknesses of these outputs are discussed on a form-specific basis to evaluate their future applications.

Figure 1: Fabric folding studies, images sourced from Studio Samira Boon (2024)
(a) *Tsuru x Brighton College* project completed in 2024
(b) *Kumo x Lightnet* project completed in 2024
(c) *HERMÈS & RDAI* project completed in 2022.

2. METHODOLOGY

The methodology of this study is developed based on the dynamic fabric mold system generated by fabrigami technique which is offered by Akçay Kavakoğlu (2020) for exploring the novel tectonics of fabric-formed concrete. The progress includes three modeling stages: algorithmic modeling, 3D geometric modeling, and analog modeling **(Figure 2)**. The research methodology comprises three stages: i) the selection of the crease pattern for the unit, ii) the design of the deployable formwork system based on the selected unit pattern, and iii) the casting of concrete into fabric molds.

I. The selection of folding pattern: Initially, a crease pattern is chosen to form a unit.

II. The production of foldable formwork through digital craftsmanship: This stage involves designing a deployable formwork system using fabric, leveraging the fabrigami technique. Given that the resulting form will impact its structure, initial emphasis is placed on designing connection details within the system. Various modeling methods are employed to conduct hinge experiments, and ultimately, the designed formwork structure is integrated with different types of fabric.

III. The casting of concrete into fabric molds: Various concrete experiments are conducted on deployable fabric molds.

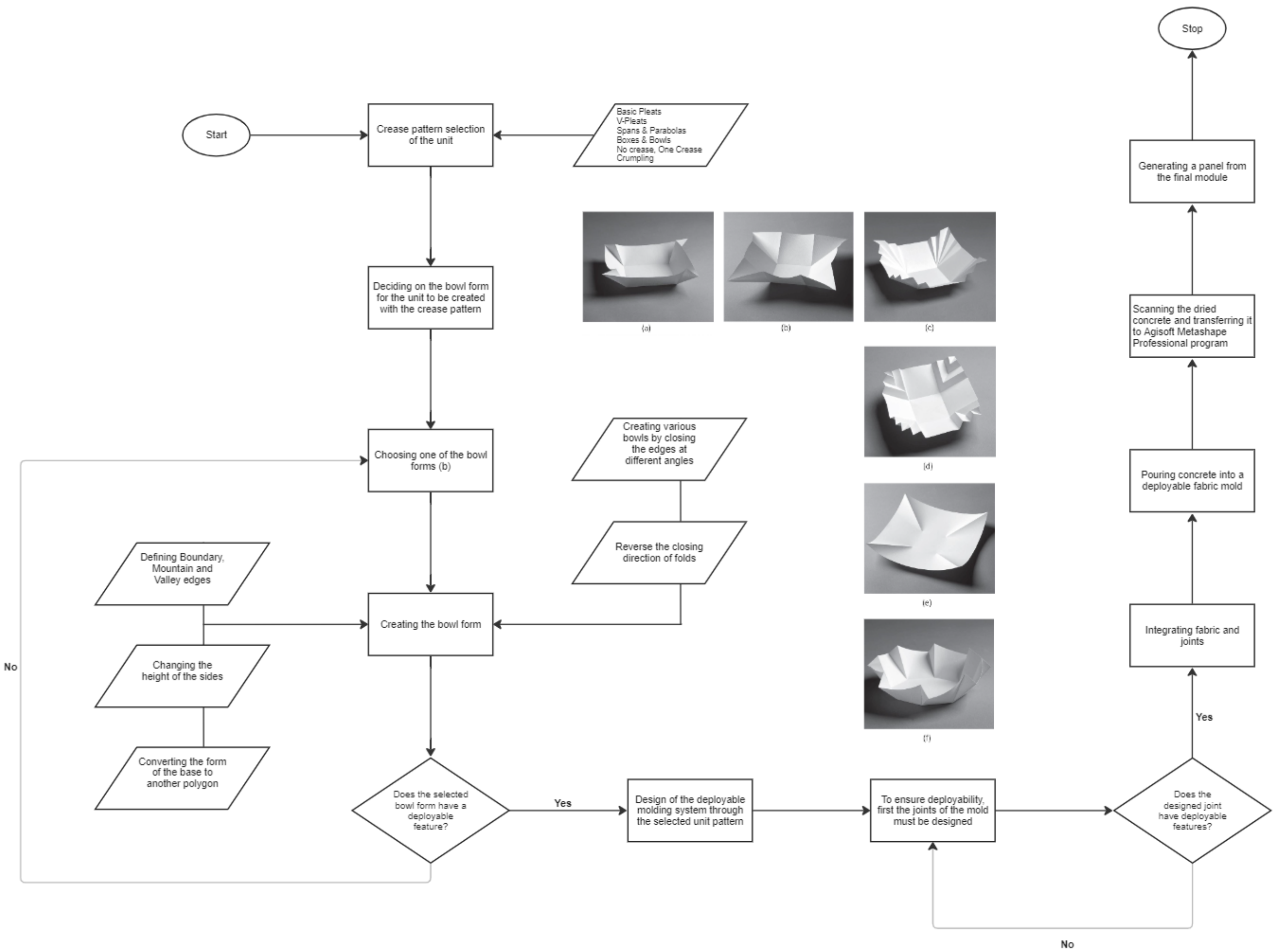


Figure 2: Flowchart of the process and illustration of bowl forms adapted from Jackson's (2011) book.

2.1 The Selection of Folding Pattern

The bowl form is selected as the basis for the unit to be created using the crease pattern. Due to the broad design parameters of bowl forms, it is possible to produce bowls in a wide variety of shapes. Various modifications are feasible, such as altering the height of the sides, changing the base to another polygon, creating different bowls by closing the edges at various angles, or reversing many folds. These variations, when combined in different ways, can result in highly diverse forms. In Jackson's book, *Folding Techniques for Designers: From Sheet to Form*, he demonstrates the folding techniques for creating bowl forms, progressing from simple to complex, and identifies six distinct bowl units **(Figure 3).**

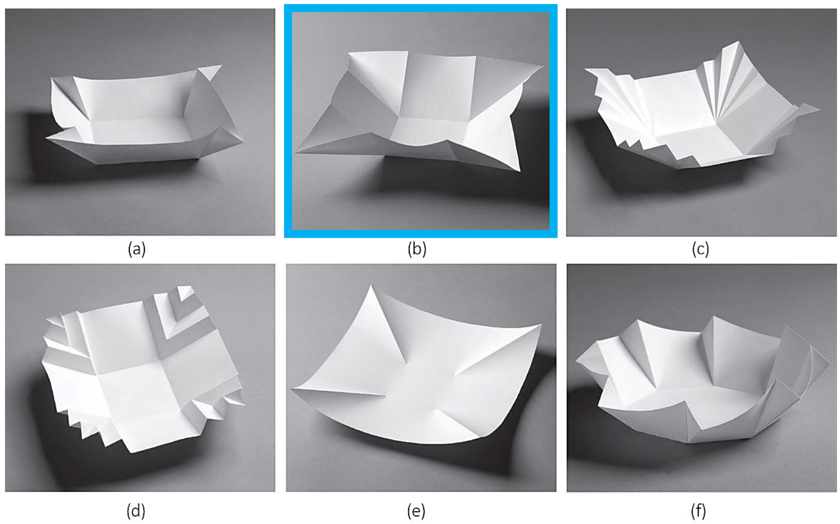


Figure 3: Six different types of bowl forms (Jackson, 2011).

In this study, the unit (b) is selected from among the bowl forms presented in the book. When comparing all the units, the units labeled (d) and (c) are not chosen due to the presence of excessive curvature at the ends of the diagonal axes, which could cause fabric folding difficulties and require more material for the rigid framework of the mold. Similarly, the unit (e) is excluded as it does not provide a suitable cavity for pouring concrete. The remaining units labeled (a) and (f) are also dismissed due to their inward protrusions, which could potentially cause issues during the demolding process.

One of the key advantages of the selected unit (b) is relatively its simple form, which allows it to adapt to the fabric and facilitate folding. This feature enables the use of a variety of materials, from paper to fabric, in the creation of dynamic molds. Such versatility supports sustainability by allowing the use of different design options at low-cost and maximizing the efficient use of available materials. Another significant advantage of the chosen bowl form is its capacity for rapid and mass production, which simplifies the creation of numerous units and modular designs. Furthermore, the ability to alter the folding direction of the unit, folding its ends either inward or outward, provides various design alternatives. The selected unit has two different versions: inward-facing and outward-facing, to be utilized in subsequent molding stages. However, considering that the inward-curving version would hinder the removal of concrete material once poured, the outward-facing version is preferred.

2.2 The Production of Foldable Formwork through Digital Craftsmanship

Following selecting the crease pattern to create the unit (b), the boundary, mountain, and valley details of the chosen unit are first digitally drawn. These edges are then defined within a computational design environment. Using the simulation component available in the Crane plug-in, the folding motion is simulated, and the resulting forms are observed **(Figure 4).** In the physical environment, the design of the connection details, which enable the system's mobility, is crucial for creating a deployable mold system. In this context, the connection details are initially addressed, and various connection designs are digitally generated to explore different possibilities and save time. Rapid prototyping methods are employed, with a 3D printer used as a manufacturing tool for these designs. The fundamental question at this stage is: *How can the movement of the system be achieved with joints?* Based on the answer to this question, the materials to be used are selected. Wooden rods are chosen for the strength of the system's basic framework, while a flexible material called *Thermoplastic Polyurethane-TPU* is selected for the joints to ensure flexibility.

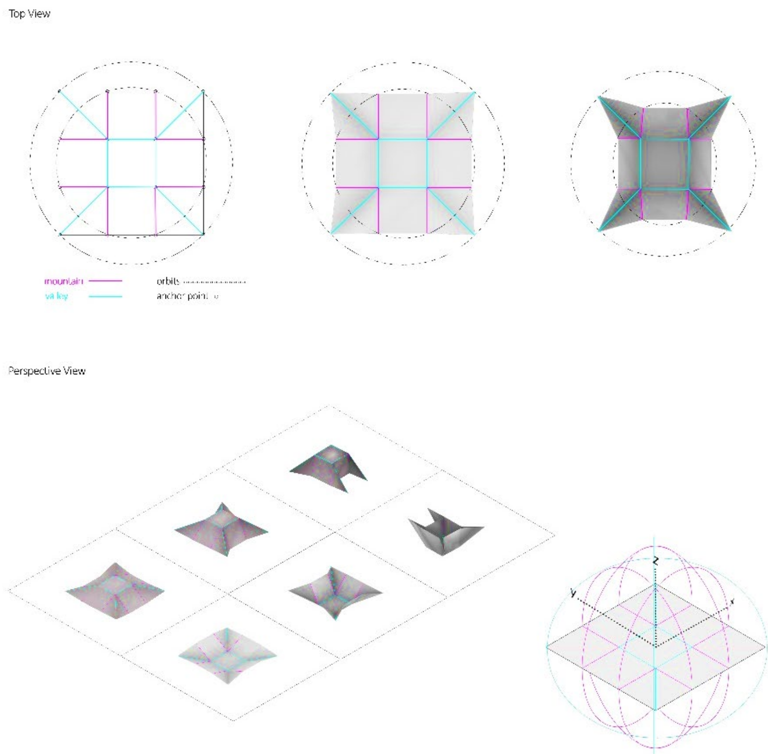


Figure 4: Identifying edges and exploring folding motion.

2.2.1 Joint Experiments

After deciding on the material selection, a joint structure is created in a computational design environment using open-source code from Parametric House (2022) to develop an idea for the connection detail. The joints are then integrated into the mold structure, as shown in **Figure 5**. To test the designed joint in a physical environment, it is produced using *Thermoplastic Polyurethane* through additive manufacturing, as depicted in **Figure 6**.

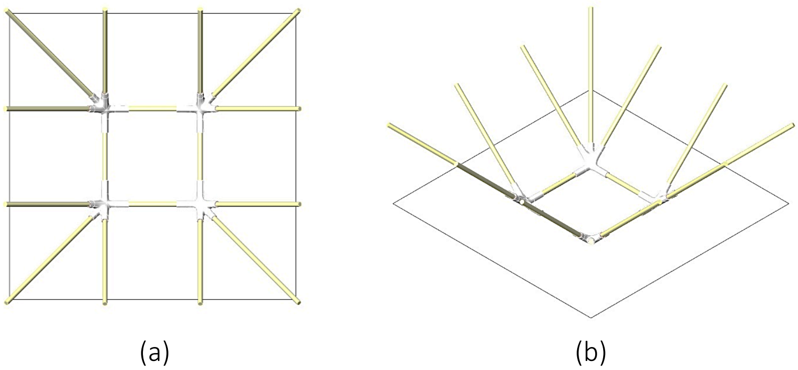


Figure 5: Views of the molding system consisting of joint type-1
(a) Top view,
(b) Perspective view.

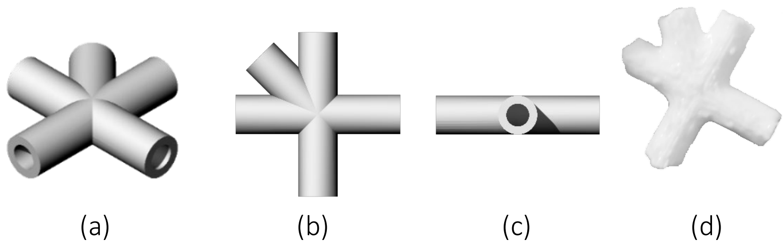


Figure 6: Views of joint type-1
(a) South-east view,
(b) Top view,
(c) Front view,
(d) 3D-printed model.

Joints are designed in a 3D geometric modeling environment for the second attempt. In this design, a central cylinder surrounded by cylindrical tubes is incorporated. It is aimed to allow the wooden bars of the formwork structure to fit into the cylindrical tubes with this configuration. The produced detail is fabricated entirely with TPU **(Figure 7).**

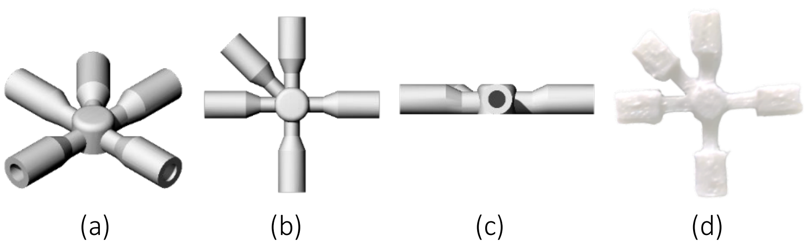


Figure 7: Views of joint type-2
(a) South-east view,
(b) Top view,
(c) Front view,
(d) 3D-printed model.

In the third attempt to achieve the desired state, the concept of combining a sphere in the center with surrounding rings to attach it to the wooden frame has emerged. Additional cylindrical tubes are designed to fasten the wooden bars **(Figure 8).**

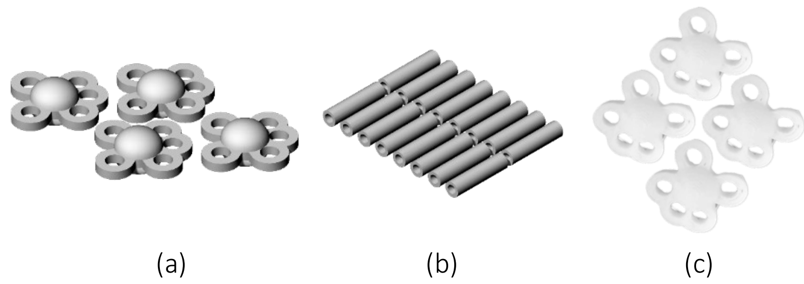


Figure 8: Views of joint type-3 (a) Sphere detail, (b) Pipe profile detail, (c) 3D-printed model.

To further enhance the deployable effect in the system, metal nuts are employed at the central parts of the joints. Around these nuts, pipe profiles fabricated with TPU are connected using flexible wires **(Figure 9).**

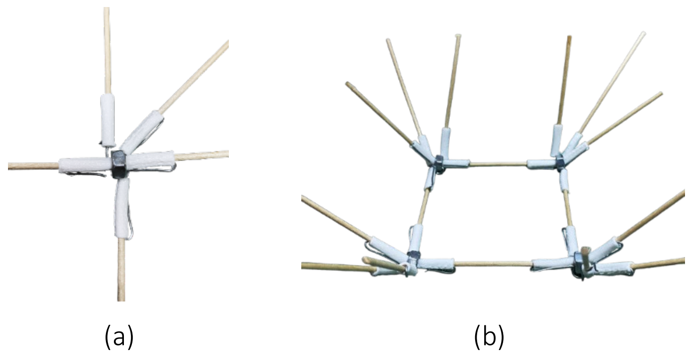


Figure 9: Views of joint type-4 (a) Metal nut detail, (b) Integrating joints into the system.

In the latest joint attempt, a sphere designed in a 3D geometric modeling environment is created to facilitate the connection of five wooden rods emerging from the central piece. These components are then manufactured using a 3D-printer. At this stage, it is crucial to ensure that the central piece has sufficient clearance to accommodate the pipe profiles connecting to the sphere. The radius of this clearance is adjusted through the production of physical prototypes **(Figure 10)**.

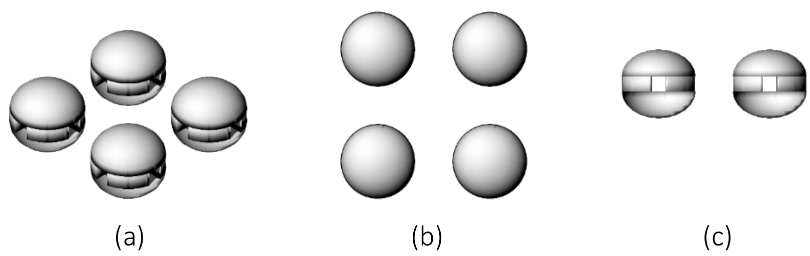
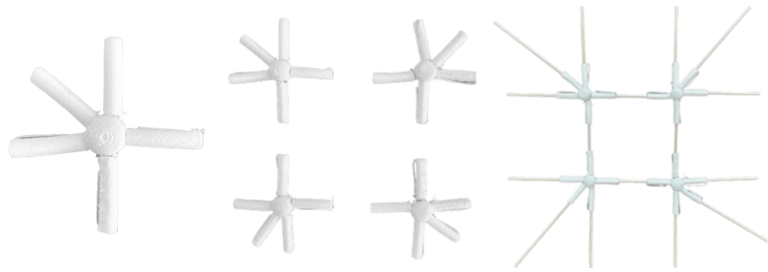


Figure 10: Views of joint type-5 (a) South-east view (b) Top view, (c) Front view.

To enhance the strength of the joint points for improved performance during concrete pouring *Biopolymer Polylactic Acid-PLA* is used for the central piece. After completing the 3D printing process, wires are integrated into the pipe profiles through this sphere **(Figure 11).** Below, it is shown that the deployable feature in the system is provided **(Figure 12).**



(a) (b) (c)

Figure 11: Views of joint type-5
(a) 3D-printed model of a single unit,
(b) Total joints used in the unit,
(c) Integrating joints into the system.

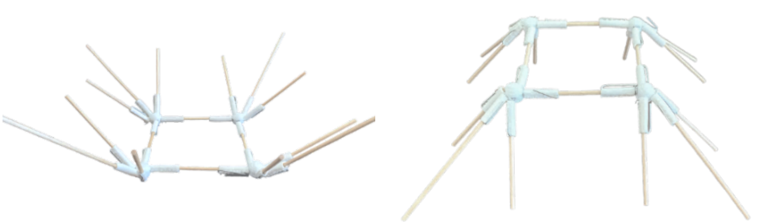


Figure 12: Examining the deployable feature of the mold
.

2.2.2 Fabric Experiments

Subsequent to designing the mold system, the next phase involves integrating this structure with fabric. In this regard, a kitchen-cloth fabric composed of 70% cotton and 30% polyester was selected to assess its flexibility as fabric type-1. The fabric is cut to 21x21 cm to match the unit size. To ensure precision, a two-dimensional structure of the unit is created by sewing stitches onto the fabric using a sewing machine, followed by sewing another piece of fabric on top of these stitches. This method allows for the integration of wooden bars into the fabric system by passing through these interstitial spaces **(Figure 13).**

Figure 13: Integrating fabric type-1 with the mold system and discovering its deployable feature.

To explore different behaviors of concrete in subsequent stages, white-flannel fabric composed of 100% cotton, which is thinner and more flexible compared to fabric type-1, is chosen. Similar to the first fabric, a piece of fabric is cut to match the size of the unit. Stitch-marks are made on the fabric to align the wooden sticks correctly. Additional pieces of fabric are sewn on top of these stitches. This process creates intermediate spaces through which the wooden rods could pass, similar to fabric type-1 **(Figure 14).**

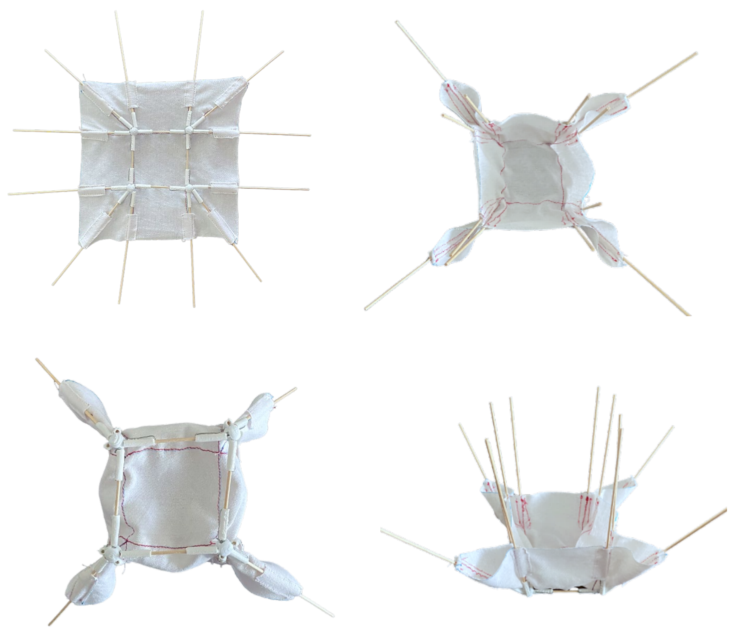


Figure 14: Integrating fabric type-2 with the mold system and discovering its deployable feature.

2.3 The Casting of Concrete into Fabric Molds

To observe the behavior of concrete in formwork systems created with different types of fabrics, various experimental setups are established. Initially, an experimental setup is prepared using fabric type-1. In the initial stage, to prevent concrete adhesion to the mold and facilitate multiple uses of the same mold, a light stretch-film is placed inside the mold. For preparing the concrete mixture, a ratio of 3 parts cement to 2 parts water is used to achieve a fluid consistency that ensures the mixture is not excessively watery. This prepared mixture is poured onto the stretch-film and left undisturbed for approximately twelve hours to allow the concrete to dry and take its full shape.

In experiments involving fabric type-2, a mold structure is constructed to investigate dynamic factors such as wind and gravity. The mold made of fabric type-2 is integrated into this structure for testing purposes **(Figure 15).** In these experiments, concrete mixtures of different weights are prepared, and the behavior of the concrete is observed. Keeping other variables constant, only the ratio of the mixtures is changed. As in the previous stages, stretch-film is placed inside the mold, and concrete is poured. After waiting for approximately twelve hours, the dried concrete is removed from the mold.

Figure 15: Mold structure where the deployable fabric-formwork will be placed.

3. RESULTS

3.1 Joint Experiment Results

The design of the connection details was of paramount importance in order to achieve a deployable effect and to create a dynamic mold system. Accordingly, prototypes were manufactured utilizing a range of modeling techniques, with multiple trials conducted to further improve the system. The outcomes of these trials are presented in the table below **(Table 2).**

Table 2: Positive and negative situations obtained from joint experiments.

ANCHOR POINT TYPE	OUTCOMES
Type1	• Although there were no errors during the production-phase, the deployable effect observed in the digital environment was not replicated when the system was tested in the physical environment.
Type2	• The second designed joint encountered some errors during production; however, after several printing attempts, it was successfully fabricated without any issues. • Despite allowing the wooden bars to move due to the flexibility of the joint material, it does not exhibit deployable characteristics. The bars could flex but were unable to be securely fixed in different positions or return to their original positions. • Following the tests, it was found that 3D printing the entire system as a single unit was not successful, prompting the decision to produce parts separately.
Type3	• Upon examination of the physical prototype, it was observed that printing with TPU posed no issues. However, it was noted that the joints were too large, potentially affecting the aesthetic appearance and precision of the shape when pouring concrete. • It was determined that the pipe profiles were suitable for subsequent stages, but the other parts proved unsuitable.
Type4	• The system was exhibited deployable features, operated successfully. However, the potential to create a structure similar to the space truss system was questioned. In this context, it was found that a design principle used in space frame systems, which facilitates the convergence of multiple beams at a single point, could be adapted for this study.
Type5	• In all previous phases of 3D printing, all parts were printed using TPU. However, issues arose during the printing of the spheres with TPU due to the small size of the holes in the center. Consequently, while the tube profiles were reprinted with TPU, the central sphere was printed using the harder. • This method facilitated the production of all components using advanced fabrication technologies and demonstrated the best deployable features of the system.

NO	FabrIc Type	MIxIng RatIo (Cement to water)	Is It suspended In the aIr?	Outcomes
1st	Type1	3:2	No	• The effect of dynamic factors during the drying process of concrete is reduced; therefore, a more static situation is observed. This revealed that the top part of the final product was flat, while only the side parts were curved. • It was observed that using stretch-film to contribute to the reusability and cleanliness of the mold had a positive effect. • Since no breakage was observed in the produced concrete mixture, it was concluded that the concrete mixture was successful. • It was determined that the desired performance could not be fully achieved due to the kitchen-cloth fabric being a bit stiff.
2nd	Type2	2.5:1.5	Yes	• The concrete was not spread adequately, resulting in a less pronounced curvature compared to the experiments with a higher weight. • Cracking occurred at the left edge of the concrete unit, and deformation was observed in the shape
3rd	Type2	3:2	Yes	• The use of a more flexible flannel fabric and an optimized concrete mix ratio facilitated more effective spreading of the concrete. • No cracking was observed along the edges of the concrete unit.
4th	Type2	3.5:2	Yes	• Due to excessive weight and the effects of gravity, a more pronounced bulge developed at the central region of the concrete unit compared to the other areas. •No deformation was observed in the produced concrete unit.

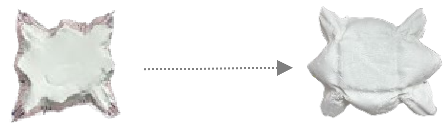
Table 3: Outcomes obtained using different fabric molds.

3.2 Fabric Experiment Results

In order to observe the behavior of concrete on fabric, a variety of fabrics were employed, including both rigid and flexible materials. Furthermore, in the second, third, and fourth experiments, dynamic factors were incorporated into the system to examine the concrete's behavior. The results of the four experiments are presented below **(Table 3).**

Different concrete mixtures were poured into fabric molds made of Fabric Type-1 and Fabric Type-2, and the resulting products are listed below **(Table 4).** The concrete dried in approximately twelve hours and was removed from the mold without sticking.

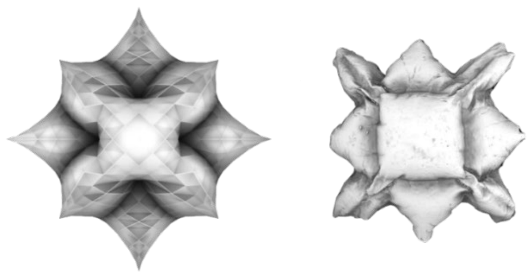
Table 4: Comparison of the resulting concrete outputs.

Order of experiment	Views
1st	
2nd	
3rd	
4th	

3.3 Comparing the Physical Model to Computational Model

Based on the data obtained from scanning the concrete unit, it was observed that the edges of the shape formed a longer profile compared to other sections, as the fabric mold was suspended from the fixed wooden formwork at its ends. This characteristic was successfully transferred to the digital environment.

However, when simulating the behavior of the concrete in a computational design environment, a shape with similarly curved edges, like the one created in the physical environment, could not be achieved, and the digital simulations did not fully align with the physical models. Further research is needed to investigate this inconsistency **(Figure 16).**



(a)

(b)

Figure 16: Comparison of computational model (left) and scanned digital model (right)
(a) Top view,
(b) Front view.

4. MODULAR DESIGN OF MICRO-SCALE FABRIC-FORMWORK

In this study, a fabric-formwork was designed using a selected crease pattern, enabling the production and arrangement of concrete units. At this juncture, it is essential to consider the potential applications of these modular concrete units. Specifically, understanding *how this unit can be utilized to create modular designs and in what context these designs can be implemented* is crucial. In this regard, a concrete unit was defined in a computational design environment, and an algorithm was developed to generate configurations of this unit in a grid-based arrangement at various angles. Visual representations of these configurations at 30, 45, and 60 degrees were subsequently created **(Figure 17).** A configuration comprising two concrete units is shown in the physical environment below **(Figure 18).** It is hypothesized that the resulting modular design could be used in the future as an interior wall panel, an exhibit element in an art gallery, or as an architectural element on the facade of a building in larger-scale applications.

Figure 17: Modular state of the unit at 30, 45 and 60 degrees respectively.

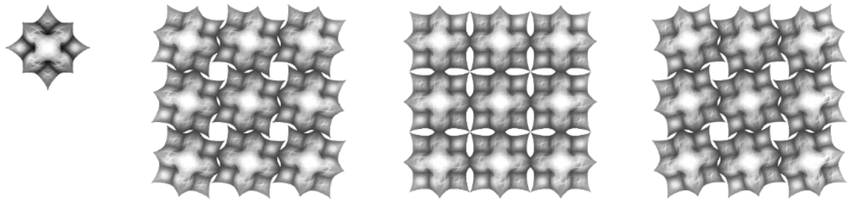


Figure 18: A configuration consisting of two concrete units in the physical environment.

5. DISCUSSION

The shaping of concrete has evolved with the development of various construction methods over time. This evolution stems from the desire to eliminate the use of disposable, heavy, and bulky molds commonly employed in the construction industry. This study, conducted through the design of flexible fabric molds, introduces a mold system that, while differing in the materials used, aligns with the reusability aspect of systems developed by Meibodi & Tessmann (2014) and Szabo et al. (2019). On the other hand, although Lloret-Fritschi et al. (2023) demonstrated the successful production of concrete using wax-coated paper molds, which offered the potential for lightweight mold systems, their approach required the peeling of the mold to remove the concrete.

The most significant distinction of this study from existing concrete mold systems in the literature is the integration of a hinge mechanism into the dynamic mold system. This mechanism features a hinge system that allows five wooden rods to pass through a single joint, creating multiple degrees of freedom. This approach is analogous to the reconfigurable units with multiple degrees of freedom designed using metamaterials by Overvelde et al. (2016). In this context, while existing dynamic molds in the literature, such as the diagonal movement in Meibodi & Tessmann's (2014) mold or the two-state mold production in Lloret-Fritschi et al. (2023), exhibit limited movement, this study introduces a more versatile system.

There are also notable similarities between this study and other concrete mold systems. One such similarity is with the work titled "P_Wall" by Andrew Kudless, founder of MATSYS Design Studio, which employs computational methods to produce organic textures using flexible fabric molds. Additionally, the method of securing the fabric at specific points in Kudless's work parallels the construction approach in this study. However, unlike the MATSYS approach, which uses fixed wooden dowels for mold construction, this study integrates a movable hinge system into the fabric mold. Furthermore, this study bears resemblance to the works of Meibodi & Tessmann (2014), particularly in the inclusion of digital craftsmanship in the concrete mold production process.

6. CONCLUSION

This research evaluates the outcomes of applying the Fabrigami technique to flexible fabric formwork within the framework of fabric formwork, concrete, and digital craftsmanship. The study distinguishes itself from other works through the design of a multi-degree-of-freedom hinging system. Although the outcomes produced in this study focused on the single-target optimization of the form by fixing the foldable mold at specific points to a rigid wooden frame, the hinge system designed in this paper offers the potential to create unexplored form alternatives. By utilizing both fixed and movable elements, it is possible to explore different variations by securing the dynamic fabric mold at specific points during its movement and then pouring concrete.

Additionally, the repeated use of the same mold in three experiments conducted with fabric type-2, demonstrates the reusability of this mold. This offers a sustainable alternative to the heavy and single-use molds commonly used in the construction industry.

Due to limited access to resources, the dynamic fabric formwork designed and produced in this study was not fabricated on a large scale and was constrained by the build volume of the 3D printer. To advance this research, future studies could explore the application of dynamic formwork on a macro scale, potentially in combination with robotic fabrication techniques, to address the structural challenges of concrete structures that tend to collapse beyond a certain height in digital casting. Moreover, the assembly of the produced concrete units was beyond the scope of this study; therefore, future research could focus on developing a detailed assembly system to test its applicability at different scales.

When comparing the 3D-scanned model of the concrete unit produced in this paper with its digital simulation, a 100% match was not observed. In this context, future experimental work could focus on improving the accuracy of digital physical models by addressing production-related issues and incorporating more comprehensive datasets on the behavior of fabric and concrete into digital tools, thereby generating more precise predictive outcomes.

Acknowledgments

This study was conducted as part of the Digital Architectural Design & Modelling course during the fall semester of the 2023-2024 academic year within the *Architectural Design Computing* Graduate Program at Istanbul Technical University. I would like to extend my sincere gratitude to Prof. Dr. Leman Figen Gül, Assoc. Prof. Dr. Ayşegül Akçay Kavakoğlu, Res. Assist. Fatih Uzun, and Res. Assist. İnanç Şencan, the coordinators of the course, for their valuable contributions. Additionally, I am deeply thankful to architect Furkan Bayır for providing me with the opportunity to work with digital fabrication.

Author Contributions

Writing—original draft preparation- Z.G.; Data Acquisition- Z.G.; Data Analysis/Interpretation- Z.G.; Critical Revision of Manuscript- Z.G., A.A.K., and L.F.G; Material and Technical Support- Z.G.; Supervision A.A.K., and L.F.G. All authors have read and agreed to the published version of the manuscript.

Conflict of Interest Statement

The authors declare that there are no financial or other material conflicts of interest that could have influenced the results or interpretations presented in this study.

Funding Statement

The authors declare that there was no financial support for this study.

Institutional Review Board Statement

The authors declare that an ethics committee statement is not required for this study.

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A Proposal for a Material-Focused AI-Supported Design Process: From Natural Material to Artificial Intelligence

Asena Kumsal Şen Bayram[1], Yekta Özgüven[2], Nadide Ebru Yazar[3], Erincik Edgü[4], Sebahat Sevde Sağlam[5]

ORCID NO: 0000-0002-1131-6073[1], 0000-0003-0899-1307 [2], 0000-0002-3278-5303 [3], 0000-0003-0899-1307 [4], 0000-0002-4186-4759[5]

[1,3,4,5] Maltepe University, Architecture and Design Faculty, Department of Architecture, Istanbul, Türkiye

[2] Maltepe University, Architecture and Design Faculty, Department of Architecture in English, Istanbul, Türkiye

In this study, the process and outcomes of the "[Removed for Blind Review]" workshop, which was organized to understand the different layers that emerge from the integration of artificial intelligence (AI) into the traditional design process, are discussed. The workshop, conducted with 43 students from the disciplines of Architecture, Interior Architecture, and Ship and Yacht Design, aims to highlight the differing thought patterns of the participants throughout the process, focusing on the relationship between material and AI. This study employed the "observe-think-act" method, and structured where participants assumed the role of researchers within this method. In the first stage of the workshop, participants produced their biopolymer materials. The design studies focusing on the material properties are expected to occur within a composition where the material is considered from the user's perspective. The material experience, is possible through the identification of the sensory, semantic, emotional, performance, and potential characteristics of the material. In the second stage, participants developed forms using Midjourney, utilizing the criteria they set for their materials. The final stage concerns how much participants altered their formulations while physically producing the AI-assisted designed forms and how these changes impacted the renewed material experience characteristics. At the end of the process, most participants modified their initial formulations to produce the AI-assisted form. The changes in the new formulations primarily occurred in the keywords associated with performance and potential, while a limited number of changes were made in those related to semantic, sensory, and emotional parameters. This result indicates that despite the influence of artificial intelligence, the perceptual subjectivity during the participants' initial interaction with the material was not lost.

Received: 09.07.2024
Accepted: 15.09.2024

Corresponding Author:
asenakumsalsenbayram@maltepe.edu.tr

Şen Bayram, A.K., Özgüven, Y., Yazar, N. E., Edgü, E., & Sağlam, S.S., (2024). A Proposal for a Material-Focused AI-Supported Design Process: From Natural Material to Artificial Intelligence, JCoDe: Journal of Computational Design, 5(2), 211-234. https://doi.org/10.53710/jcode.1512903

Keywords: Material experience, Bio-Polymer, Artificial Intelligence, Informal learning.

Malzeme Odaklı Yapay Zekâ Destekli Bir Tasarım Süreci Önerisi: Doğal Malzemeden Yapay Zekâya

Asena Kumsal Şen Bayram[1], Yekta Özgüven[2], Nadide Ebru Yazar[3], Erincik Edgü[4], Sebahat Sevde Sağlam[5]

ORCID NO: 0000-0002-1131-6073[1], 0000-0003-0899-1307 [2], 0000-0002-3278-5303 [3], 0000-0003-0899-1307 [4], 0000-0002-4186-4759[5]

[1,3,4,5] Maltepe Üniversitesi, Mimarlık ve Tasarım Fakültesi, Mimarlık Bölümü, İstanbul, Türkiye

[2] Maltepe Üniversitesi, Mimarlık ve Tasarım Fakültesi, İngilizce Mimarlık Bölümü, İstanbul, Türkiye

Bu çalışmada, geleneksel tasarım sürecine yapay zekâ (YZ) entegrasyonu ile ortaya çıkan farklı katmanları okuyabilmek amacıyla düzenlenen "[Hakem değerlendirilmesi için çıkarılmıştır]" başlıklı çalıştayın süreci ve sonuçları tartışılmaktadır. Mimarlık, İç mimarlık ve Gemi ve Yat Tasarımı disiplinlerinden 43 öğrenci ile gerçekleştirilen çalıştay, katılımcıların süreçteki farklılaşan düşünme biçimlerini, malzeme ve YZ ilişkisi üzerinen ortaya koymayı hedeflemektedir. Bak-düşün-eyleme geç yönteminin kullanılıldığı çalışmada, katılımcıların bu yöntemdeki araştırmacı rolüne büründükleri bir süreç kurguanmıştır. Çalıştayın ilk aşamasında katılımcılar kendi biyopolimer malzemelerini üretmişlerdir. Malzeme özelliklerine odaklanan tasarım çalışmalarının, malzemenin kullanıcı perspektifinden ele alındığı bir kompozisyon içinde gerçekleşmesi gerekmektedir. Bahsedilen çalışmalara da temel oluşturan 'malzeme deneyimi', malzemenin duyusal, anlamsal, duygusal, performans ve potansiyel özelliklerinin tanımlanması ile mümkündür. Katılımcılar, reçetesini oluşturdukları malzemelerin belirledikleri ölçütlerini girdi olarak kullanarak, çalıştayın içinci aşamasında Midjourney ile form geliştirmişlerdir. Çalıştayın son aşaması, YZ destekli tasarlanan formu fiziksel olarak üretirken, katılımcıların malzeme reçetelerinde ne ölçüde değişiklikler yaptıkları ve bu değişikliklere göre yenilenen malzeme deneyimi özellikleri ile ilgilidir. Süreç sonunda çoğu katılımcının, ilk malzeme reçetelerini, YZ destekli tasarlanan formu fiziksel olarak üretmek için değiştirdiği görülmüştür. Yeni reçetelerdeki değişiklikler büyük oranda performans ve potansiyel parametrelerinde belirtilen anahtar kelimelerde gerçekleşmiş; anlamsal, duyusal ve duygusal parametrelerde belirtilen kelimelerde sınırlı sayıda değişiklik yapılmıştır. Bu sonuç, YZ etkisine rağmen, katılımcıların malzeme ile olan ilk etkileşimleri sırasındaki algısal öznelliğin kaybolmadığını göstermektedir.

Anahtar Kelimeler: Malzeme deneyimi, Biyo-polimer, Yapay zekâ, Enformel öğrenme.

Teslim Tarihi: 09.07.2024
Kabul Tarihi: 15.09.2024

Sorumlu Yazar:
asenakumsalsenbayram@maltepe.edu.tr

Şen Bayram, A.K., Özgüven, Y., Yazar, N. E., Edgü, E., & Sağlam, S.S., (2024). A Proposal for a Material-Focused AI-Supported Design Process: From Natural Material to Artificial Intelligence, JCoDe: Journal of Computational Design, 5(2), 211-231. https://doi.org/10.53710/jcode.1512903

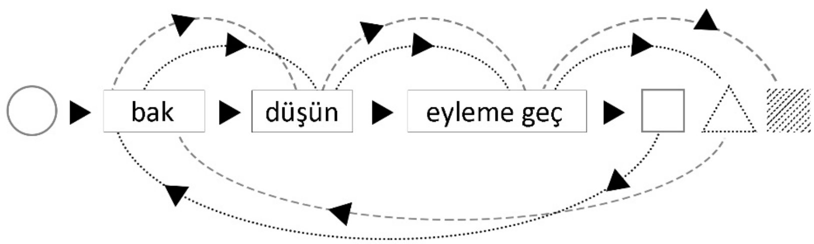
1. GİRİŞ (INTRODUCTION)

Toplumsal, ekonomik ve teknolojik eğilimlerin bilgi odaklı bir yapıya geçişi ile yaşanan çok boyutlu dönüşümler, tasarım düşüncesini, araçlarını, ortamlarını ve yöntemlerini de etkilemektedir. Günümüzde katı olan her şeyin buharlaştığı görüşünden (Berman, 2004) hareketle, gerçek olan ve sanal olan arasındaki farkın önemini yitirdiği (Baudrillard, 2003), herşeyin birliğe evrilerek karmaşıklaştığı ve bir yandan da atomize olduğu (Poincaré, 2001) açıktır. Bu durumda, tekil ögeler yerine, birbiri ile ilişkisiz görünen ögeler arasında yeni bağların keşfedildiği bir aradalıktan ve birliktelikten söz etmek mümkün hale gelmiştir. Böylesi bir birliktelik, hayalgücü ve yaratıcılık gibi kavramlara temellenen tasarım disiplinleri için geniş bir düşünme ve üretme olanağı sunmaktadır. Tasarım sürecinin, doğası gereği, çok disiplinli ve işbirlikçi yapısı, günümüzde bilgi teknolojilerinin tasarım alanına entegrasyonu ile sınırsız sayıda ve biçimde yeni birliktelik ortamlarının oluşmasına yol açmıştır. Bu ortamlar, tasarım alanında karar verme süreçlerinin çok katmanlı yapısını bir yandan geliştirirken, bir yandan da çok sayıda yeni katmanların oluşmasına olanak sağlamıştır (Dave ve diğ., 2018).

Teknolojinin gündelik hayatın merkezine yerleşmesiyle birlikte, tüm dünyada sanal öğrenme ortamları günümüzde tasarım eğitimine dahil edilmiş ve öğrenme sürecine aktif katılım biçimlerinin farklılaşmasına yol açmıştır. Tasarım eğitimi, bu yeni birlikteliklerin ve katmanların en belirgin biçimde ortaya çıktığı alanlardan biridir. Öğrenilen bilginin doğrudan uygulamaya aktarılmasına izin vermeyen formel eğitim ortamlarına, farklı ve geniş açılımlar sunan enformel eğitim ortamları eklenmiştir (Hoff, 2001). Hatta, günümüzde enformel öğrenme ortamları, öğrencilere bilginin deneyime bağlı öğrenilmesini sağlayan çeşitli yöntemler sunması sebebiyle, formel öğrenme ortamları kadar önemli bir hale gelmiştir (UNESCO-UIS, 2012). Bireyin öğrenme sürecine kendi isteğiyle katıldığı bu enformel öğrenme biçiminin etkin ve kalıcı olabilmesi ise, kendisini öğrenme ortamının bir parçası haline getirmesi ve etkileşimsel öğrenme araçlarını kullanması ile mümkündür (Csikszentmihalyi, 1997). Bu öğrenme ortamlarının sunduğu geniş yelpaze, son yıllarda tasarım eğitimi konulu çalışmaların formel eğitim yerine enformel eğitim ortamlarına odaklanmasına yol açmıştır.

Bu bağlamda, tasarım sürecine yeni nesil dijital olanakların entegrasyonu ile ortaya çıkan farklı birliktelik ortamları ve katmanlarını okuyabilmek amacıyla bir çalıştay düzenlenmiştir. Bir enformel öğrenme ortamı olarak oluşturulan çalıştayda, farklı tasarım disiplinlerden öğrenciler katılımcı olarak yer almışlardır. Böylelikle, geleneksel tasarım süreçlerine dijital ortamların entegrasyonunun yanı sıra, farklı disiplinlerdeki aktörlerin yeni birlikteliklerin ortaya çıkış sürecindeki farklı davranış biçimleri de yeni katmanlar olarak ele alınmıştır. Bu doğrultuda, bu araştırma, "Doğal Malzemeden Yapay Zekaya" başlıklı çalıştay sürecini ve sonuçlarını, katılımcıların süreçteki farklılaşan düşünme biçimleri üzerinden ortaya koymayı hedeflemektedir.

Araştırmanın metodolojisi, öğrenciyi merkeze alan enformel öğrenme biçimlerine odaklanan araştırmalarda sıklıkla tercih edilen eylem araştırması yöntemine temellenmektedir. Eylem araştırması, belirli bir süreçte deneysel hedefe doğru ilerlerken somut bir durumdaki faktörlerin birbirleriyle nasıl ilişki kurduğunu inceleyen çalışmalara verilen bir terimdir (London ve Ostwald, 2004). Eylem araştırmalarında, odak, süreçte ortaya çıkan bilgi üzerindedir. Bir eylem araştırması türü olan bak-düşün-eylem ise süreci daha tanımlı hale koymakla birlikte, bir yandan da sistematize ederek sonuç analizlerin süreçte yansımalarına izin veren döngüsel bir sistem tanımlamaktadır (Şekil 1) (Stringer, 2008). Bu nedenle, bu araştırmada bak-düşün-eyleme geç yöntemi kullanılmıştır.



Şekil 1: Bak-düşün-eyleme geç yöntemi (Stringer, 2008'den adapte edildi).
(Look-think-act method. (Adapted from Stinger, 2008)

Bu çalışmanın diğer araştırmalardan en temel farkı, araştırmacılara değil, katılımcıların süreçlerinin tariflenmesine odaklanmasıdır. Böylelikle, hem tasarım sürecinin hem de enformel öğrenme ortamının temel aktörü olan katılımcının öğrenen-öğreten-araştırmacı-karar verici olma eksenindeki rolü ve bu eksendeki değişimleri ortaya konabilecektir. Bu çerçevede, katılımcıların, her birinin tasarım sürecinde sistematik olarak tanımlanmış adımları izleyerek, bakıp, düşünüp karar verip sonraki değişikliklerine karar verecekleri bir kurguda öğrenenden araştırana doğru dönüşümleri izlenebilecektir.

Bu noktada, çalıştayın ana temasının, hem farklı tasarım disiplinlerinden gelen atölye katılımcılarının kişisel yetenek ve ilgileri ile uyum içerisinde olan hem de tüm tasarım disiplinleri için geçerli olan güncel bir konu etrafında belirlenmiş olması araştırma için büyük öneme sahiptir. Katılımcıların kendi öğrenme süreçlerini etkin olarak yönetecekleri düşünüldüğünde, tasarım ve bilgi odaklarını birlikte ele alan bir araştırmanın güncel konu ve yöntemleri içeren bir çerçevede kurgulanması gerekliliği açıktır. Bu amaçla, öncelikle tasarım ve bilgi odaklarını farklı ölçek, konu ve uygulamalarla irdeleyen araştırmalar incelenmiştir. Bu incelemelerde, günümüzde yapay zekâ (YZ) teknolojilerinin, her alana olduğu gibi, özellikle tasarım eğitimi alanındaki nüfuzu ve yardımcı rolü dikkati çekmiştir. Dolayısıyla, tasarım pratiğinde ve eğitimindeki etkinliği her geçen gün artan bu teknolojilerin (Rios-Campos ve diğ., 2023), geri bildirim (Krstić ve diğ., 2022), çözüm (Ahmad ve diğ., 2021), esneklik ve özelleştirmeye (Sadiku ve diğ., 2021) olanak sağlayan genişlikteki yapısı bu araştırma için bir zemin oluşturmuştur.

Diğer taraftan, literatürde, bilgisayar temelli teknolojilerin, tasarımcının hayal gücünü genişletme -aslında özgürleştirme- ve daha verimli tasarımların ortaya çıkışını kolaylaştırma konularında etkin bir rolü olsa da, tasarım sürecini daha çok görsel bir imgeye de indirgediği (Pallasmaa, 2007) yolunda çeşitli eleştiriler söz konusudur. Bu eleştiriler, dijital teknolojilerin tüm duyuları aktif hale getiren ve bu duyularla yürütülen tasarım sürecinde, tasarımcı ile tasarım ürünü arasında bir mesafe yarattığı görüşünü temellenmektedir. Buna göre, el çizimleri ve fiziksel maket yapımı ile yürütülen tasarım süreçleri ise, tasarımcı ile tasarım ürünü arasında dokunsal bir temasa olanak sağlamakta ve dolayısıyla da tasarımcı ile tasarım ürünü arasında bedensel ve zihinsel bir özdeşleşme ortaya koyan yaratıcılığı desteklemektedir (Pallasmaa, 2007).

Tasarım sürecinde malzemenin fiziksel olarak deneyimlenmesiyle tasarımcıda oluşturduğu hissiyat, öğrenme ve anlama açısından önemlidir. Tasarımcının, tasarım sürecinde malzeme ile olan etkileşimi, bir yandan zihindeki yaratma sürecini yönlendirirken; malzeme yalnızca sonuç ürünün belirleyicisi değil, yaratma ve yapım sürecinin doğal bir parçası olur. Böylece, her malzeme kendine özgü özellikleriyle tasarım nesnelerinin formunu, görünüşünü, anlamını ve algısını belirlemektedir. Bu bağlamda, çalıştayın kapsamı, geleneksel tasarım sürecinin belirleyici etmenlerinden biri olan malzemenin, YZ destekli teknolojilerle olan etkileşimi üzerinden süreçteki dönüşümü olarak belirlenmiştir. Çalıştay, bak-düşün-ekleme geç sürecindeki dönüşümleri daha açık biçimde irdeleyebilmek amacıyla, yaratıcılığı daha geniş ölçekte destekleyen YZ teknolojileri kullanımı ile yaratıcılığı kişisel ölçekte destekleyen yöntemlerin kullanımı birlikteliğini öngören enformel bir süreç olarak kurgulanmıştır.

2. MALZEME ODAKLI YZ DESTEKLİ BİR TASARIM SÜRECİ ÖNERİSİ

(A PROPOSAL FOR A MATERIAL-FOCUSED AI-SUPPORTED DESIGN PROCESS)

Farklı tasarım disiplinlerine ilişkin bilgilerin günümüz dijital teknolojileri ile birlikte kullanılarak, nesnelerinin tasarlanma ve üretim süreçlerindeki malzeme ve form ilişkisinin deneyim yoluyla araştırılmasını amaçlayan, yaratıcılık odaklı çalıştayın iki temel bileşeni bulunmaktadır: Biyo-polimer malzemeler ve YZ uygulamaları.

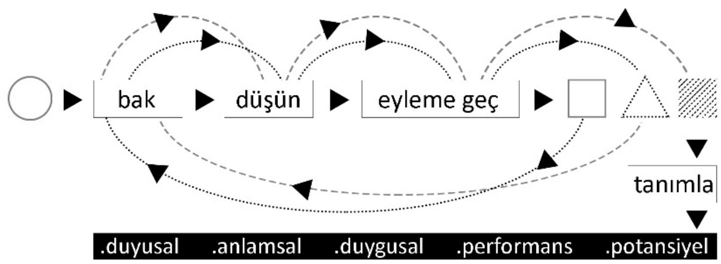
2.1 Malzeme Odaklı Tasarım: Biyo-polimer Malzemeler (Material-Focused Design: Biopolymers)

Bir malzeme ile tasarım yapmak, o malzemeyi tanımayı gerektirir. Malzeme ile 'oynamak' olarak da adlandırılan bu etkileşim, yaratıcı düşünce sürecinin ilk safhasından başlayarak sonuç ürün elde edilene kadar devam eder (Karana ve diğ., 2015). Konuyla ilgili literatür incelendiğinde, malzemelerle ilgili pürüzsüz-pürüzlü, yumuşak-sert, hafif-ağır gibi duyusal karşıtlıkların keşfedildiği malzemelerin 'doğasına' odaklanan ilk çalışmalarda, katılımcıların malzemelerin özelliklerini dokunarak deneyimlediği görülmektedir (Itten, 1975; Wick, 2000). Dünyayı tüm duyuları aracılığıyla algılayana bireylerin çevreye ilişkin deneyimini de olanaklı kılan en temel faktör dokunmadır (Pallasmaa, 2007). Dokunma, özellikle tasarım disiplinlerinin yaratıcı ve estetik kaygılarını anlamlı hale getiren görsel algılamanın da en temel bileşenidir. Zaten tam da bu nedenle, güncel çalışmalar, malzemenin hissettirdiği duyusal farklılıklar ve bu farklılıkların kullanıcı deneyimleri üzerindeki etkileri (Howes ve diğ., 2014; Chapman, 2014) gibi konulara odaklanmaktadır.

Malzeme deneyiminin bileşenlerinin incelenmesini içeren çalışmalardan İfade-Sensöryel Atlası (Rognoli, 2010), Malzeme Algı Araçları (van Kesteren, 2008), Malzeme Estetik Veritabanı (Zuo, 2010) ve Anlam Odaklı Malzeme Seçimi (Karana, 2009) bu araştırmada uygulanacak çerçeve ile benzerlikler içermektedir. Özellikle malzemelerin anlamları modeline (Karana, 2009) dayanan Anlam Odaklı Malzeme Seçimi, malzeme deneyiminde kullanıcı ile malzeme arasındaki dinamik etkileşimi görselleştirmesi bakımından önemlidir. Bu modele göre, ürün ve malzeme arasındaki ilişkileri anlayabilen tasarımcılar, malzemeleri daha bilinçli bir şekilde işleyebilmektedirler.

Malzeme özelliklerine odaklanan tasarım çalışmalarının, malzemenin kullanıcı perspektifinden ele alındığı bütünsel bir kompozisyon içinde gerçekleşmesi gerekmektedir (Wiberg, 2014; Karana, 2009). Bu nedenle malzemenin mevcut durumunu anlamak, bu durumu analiz ederek gerekli ölçütleri oluşturma ve bu ölçütlere uygun tasarımı ortaya çıkarma adımları izlenmelidir (Karana ve diğ., 2015). Bahsedilen çalışmalara da temel oluşturan 'malzeme deneyimi', malzemenin estetik (duyusal), anlamsal ve duygusal olmak üzere üç bileşen ile tanımlanmaktadır (Karana ve diğ., 2008). Takip eden çalışmalarda bu bileşenlere yapma biçimlerini ve uygulamaları da içeren performans ölçütleri eklenmiştir (Karana ve diğ., 2015).

Ancak, bu çalıştayda, nesnelerinin tasarlanma ve üretim süreçlerindeki malzeme ve form ilişkisinin deneyim üzerinden ortaya konulması amacından hareketle, duyusal, anlamsal, duygusal ve performans ölçütlerine; formu belirleme ve üretme konusunda daha geniş bir perspektif sağlamak ve malzemenin form üretimine ilişkin olumlu ve/veya olumsuz etkilerini ortaya koyabilmek adına, malzemenin potansiyeli ölçütü de analiz parametrelerinden biri olarak değerlendirilmiştir (Şekil 2).



Şekil 2: Çalıştay çerçevesi: Malzeme tasarımı-tanımlaması. Workshop framework: Material design-definition

Duyusal ölçüt, malzemenin, deneyimleyen bireyin dokunma-görme-koku gibi duyuları üzerinde nasıl bir etki oluşturduğu; anlamsal ölçüt ise malzemeyi deneyimleyen bireyin zihninde kavramsal olarak malzemeye nasıl bir içerik ve anlam yüklediğine ilişkindir. Duygusal ölçüt, malzemenin deneyimleyen bireyin duygularını nasıl tetiklediğini tariflemesini içermektedir. Performans, malzemenin fiziksel özellikleri ve yeteneklerine dair deneyimleyen bireyin düşüncelerine; potansiyel ölçüt ise malzemenin muhtemel kullanım olanaklarına ilişkin deneyimleyen bireyin zihninde barındırdığı örtük bilgiye işaret etmektedir (Karana ve diğ., 2015).

Bu çerçevede, çalışma kapsamında, duyusal, anlamsal, duygusal, performans ve potansiyel özellikleri incelenmek üzere, literatürdeki çalışmalarda da sıklıkla kullanılan biyo-polimer malzemeler seçilmiştir. Biyo-polimerler bitki, hayvan ve mikroorganizmalar gibi doğal kaynaklı malzemelerden üretilmekle birlikte; çevresel zararın azaltılması, sürdürülebilirlik, toksik olmama, biyolojik olarak parçalanabilirlik ve gübrelenebilirlik gibi özellikleri bakımından da çevre dostu malzemelerdir. Biyo-polimerlerden üretilen plastikler, geleneksel plastiğe güçlü bir alternatif olarak; medikal, tarım, otomotiv, tekstil, gıda endüstrisi ve özellikle yapı malzemesi gibi birçok sektörde gelişmiş uygulama imkânları sunmaktadır. Yapılan araştırmalar biyo-polimer ürünlerin, ticari olarak baskın olan petrol esaslı ürünler ile rekabet edebildiğini göstermekte ve bugün polimer pazarının sadece küçük bir yüzdesini oluşturmasına rağmen, gelecekte büyük oranda petrol bazlı polimerlerin yerini alabilecekleri tahmin edilmektedir (Pacheco-Torgal ve diğ, 2016; Christian, 2020; Aaliya ve diğ, 2021).

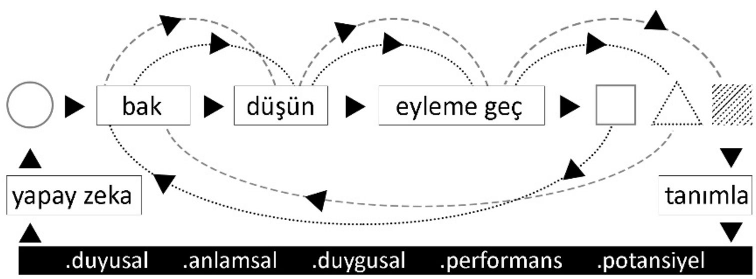
Diğer yandan biyo-polimerler, kolaylıkla erişilebilen malzemelerle, basit ortamlarda üretilebilecek bir baz reçetesine, çeşitli organik katkıların ilavesiyle, çok sayıda seçenek elde etmeye olanak sağlamaktadır. Böylece çok yönlü bir deneyim ve etkileşim olanağı yaratan sürdürülebilir biyo-polimer malzemeler, kolay üretilebilirliği ve farklılaştırılabilmesi ile tasarım sürecinin de aktif bir parçası haline gelmektedir. Ancak literatürde, atölye çalışmasının ana teması olan biyo-polimer malzemeler ile dijital teknolojileri bir araya getiren, özellikle tasarım sürecinde YZ ile olan etkileşimlerini temel alan benzer bir çalışma yer almamaktadır. Bu birliktelik, bir yandan bu araştırmanın özgün yönünü oluştururken, bir yandan da tasarım sürecinde malzemelerin kullanımı ve dönüşümü ile farklı incelemeler ortaya koyma zorunluluğunu doğurmuştur.

Malzeme alanındaki çalışmalar tekil olarak incelendiğinde, bu araştırmalarda, Large Language Models (LLM) uygulamalarının sıklıkla tercih edildiği görülmüştür. LLM'lerin malzeme biliminde başarılı bir şekilde uygulanması, iklim değişikliği, enerji güvenliği, sürdürülebilir tarım ve imalat, kişiselleştirilmiş tıbbi cihazlar ve daha güçlü bilgisayar sistemlerine erişim gibi günümüzün karmaşık toplumsal ölçekli zorluklarını ele alabilecek yeni malzemelerin keşfi, sentezi ve analizini hızlandırarak bu alanı dönüştürme potansiyeline sahiptir (Miret ve Anoop Krishnan, 2024). Ancak güncel araştırmalarda, LLM'lerin kimya (Jablonka ve diğ., 2023) ve biyolojinin çeşitli alt dalları (Lin ve diğ., 2023; Hsu ve diğ., 2022; Xu ve diğ., 2023; Cui ve diğ., 2023; Dalla-Torre ve diğ., 2023) gibi disiplinlerarası alanlarda kullanımının arttığı görülmekle birlikte, malzeme bilimine uygulanması görece yavaştır (Miret ve Anoop Krishnan, 2024). Dolayısıyla, bu çalışmanın, doğal malzeme ve YZ uygulamaları ilişkisini ve bu ilişkinin birbirleri ile karşılıklı etkileşimini tasarım süreci üzerinden inceleyen çerçevesi, yalnızca yaratıcı tasarım alanlarına değil malzeme bilimine de farklı bir bakış açısı ile katkı sağlayacak ve güncel literatürdeki önemli bir boşluğu dolduracaktır.

2.2 Tasarımda Yaratıcı bir Yardımcı: YZ (A Creative Helper in Design: AI)

Yaratıcılık, bilinçsiz düşünce/işlem (Poincaré, 1913; Miller, 2012), ani fikir ortaya çıkışı (Wertheimer, 2020), içgörü sıçramaları (Csikszentmihalyi, 1997; Simonton, 1999) ve yeniliğin üretilmesini içeren karmaşık bir olgudur (Palmiero ve diğ., 2019). Teknolojinin tasarım alanına olan etkisinin katlanarak arttığı günümüzde, yaratıcılık üzerine geliştirilen söylemler ve tartışmalar daha çok bireylerin bilişsel süreçlerine yoğunlaşmaktadır. Bu bağlamda, ortaya çıkan dijital yaratıcılık (Owen, 1996) ve hesaplamalı yaratıcılık (Colton ve Wiggins, 2012) gibi kavramlar, günümüzde YZ'nın tasarım sürecine entegrasyonu ile yeni boyutlara ulaşmıştır (Boden, 1998; Dartnal, 1994). YZ'nın çok sayıda keşif yapabilme ve ürettiği çok sayıdaki alternatif arasından bireylere seçme olanağı sağlama yeteneği, yenilikçi fikirlerin erken kavramlardan evrildiğini ve mevcut koşullara yanıt olarak rafine edildiğini öne süren (Simonton, 1999) ve yaratıcı süreci başlatmada tasarımcının probleme yaklaşımının önemini vurgulayan (Guilford, 1975) yaratıcı teorilerle de örtüşmektedir. YZ destekli (AI-powered, AI-enhanced, AI-assisted) uygulamaların bireylerin yaratıcılığı üzerindeki etkisini inceleyen çalışmalar (Miller, 2019; Fischer ve Nakakoji, 1994; King ve diğ., 2017; Graham, 2015), yaratıcı endüstrilerde (Anantrasirichai ve Bull, 2020) ve sanatta (Chen ve diğ., 2020) bir yandan YZ'nın olumlu etkisini; bir yandan da yaratıcılığı artırmak için etkileşimli kullanımının önemini vurgulamaktadır (Boden, 1998; Miller, 2019).

Teknolojik gelişmelerle birlikte, özellikle son yıllarda, metinsel girdileri görsel olarak etkileyici görüntülere dönüştürebilen YZ platformlarında büyük bir artış ve yöntemsel çeşitlilik meydana gelmiştir. Ancak, katılımcıların süreçlerinin tariflenmesine ve katılımcıların öğrenen-öğreten-araştırmacı-karar verici olma eksenindeki rolü ve bu eksendeki değişimlerine odaklanan bu çalıştayda, metinden görsele (text to image) YZ uygulamaları kullanılmıştır. Bunun en temel nedeni, tasarım sürecinde bireysel etkilerin ve dolayısıyla değişimlerin en belirgin şekilde okunabilirliği ile, bireylerin kendi ifadelerinin doğrudan tasarım sürecine dâhil edilmesidir (Şekil 3).



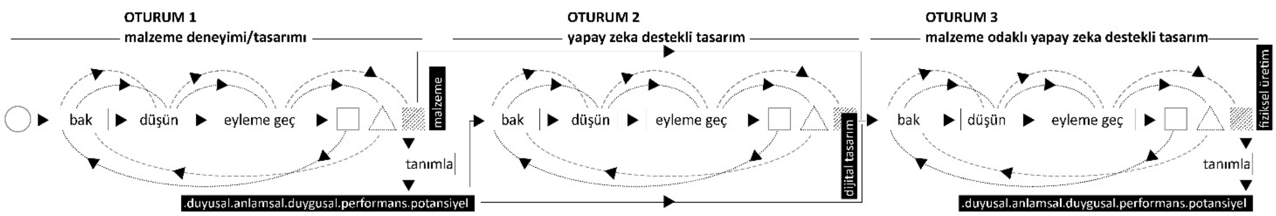
Şekil 3: Çalıştay çerçevesi: YZ destekli tasarım süreci. Workshop framework: AI-Supported design process.

Metinsel girdiler aracılığıyla tasarım fikirlerinin kavramsallaştırılması için yeni bir yol açan (Ploennigs ve Berger, 2022) ve büyük dil modelleri (LLM'ler) olarak adlandırılan bu uygulamalar, son yıllarda yalnızca tasarım alanını değil, neredeyse tüm disiplinleri şekillendirmeye başlamış ve geleceğe dair yol haritalarını değiştirmek zorunda bırakmıştır (Zhang ve diğ., 2023). Teknolojik gelişmelerle birlikte sürekli biçimde güncellenen LLM'lerin eğitim alanındaki uygulamaları ise yeni bir araştırma konusudur (Wei ve diğ, 2022). LLM'lerin eğitim alanında kullanılmasına ilişkin fırsatları, zorlukları ve sonuçları ortaya koyan çalışmalarla (Ji ve diğ., 2022; Kasneci ve diğ., 2023) bağlantılı olarak LLM'lerin eğitimde kullanımı çeşitli tartışmaları beraberinde getirmiş olsa da (Johnson, 2023), bu araçlar geleneksel öğrenme süreçlerini yeniden düşünmek için bir fırsat olarak görülebilir.

YZ'nın tasarım eğitiminde kullanımı ise, daha erişilebilir, hızlı (Bölek ve diğ., 2023) ve yaratıcı (Nast, 2023) bir paradigma değişimine işaret etmektedir. Tasarım eğitiminde YZ kullanımını konu alan araştırmalar, kompleks geometrileri oluşturabilme ve çok sayıda tasarımı çok kısa bir zaman diliminde ortaya koyabilme gibi sonuçları ortaya koymaktadır (Tong ve dig., 2023; Saadi ve Yang, 2023). Bu çerçevede, bu çalıştayda da, LLM modellerinden günümüzde yaygın kullanıma sahip, kolay anlaşılabilir bir arayüz sağlayan, OpenAI'nın DALL-E ve Stability AI'nın Stable Diffusion'ı (Hertzmann, 2022) gibi metinsel ifadelerden yüksek çözünürlüklü görüntü üretebilen Midjourney kullanılması tercih edilmiştir.

3. DOĞAL MALZEMEDEN YZ'YA SÜRECİ VE BULGULAR (FROM NATURAL MATERIAL TO AI PROCESS AND FINDINGS)

Doğal Malzemeden Yapay Zekaya başlıklı çalıştay, Maltepe Üniversitesi Mimarlık ve Tasarım Fakültesi Mimarlık İngilizce ve Türkçe, İç Mimarlık, Gemi ve Yat Tasarımı Bölümleri'nden öğrencilerin katılımlarıyla 3 oturumluk bir deneyim olarak kurgulanmıştır (Şekil 4).



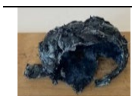
Şekil 4: Çalıştay kurgusu.
Workshop process.

Birinci oturum, farklı disiplinlerde, farklı seviyelerde eğitimine devam etmekte olan 43 gönüllü katılımcının (Tablo 1) kendi biyo-polimer malzemelerini tasarladıkları bir malzeme deneyimidir.

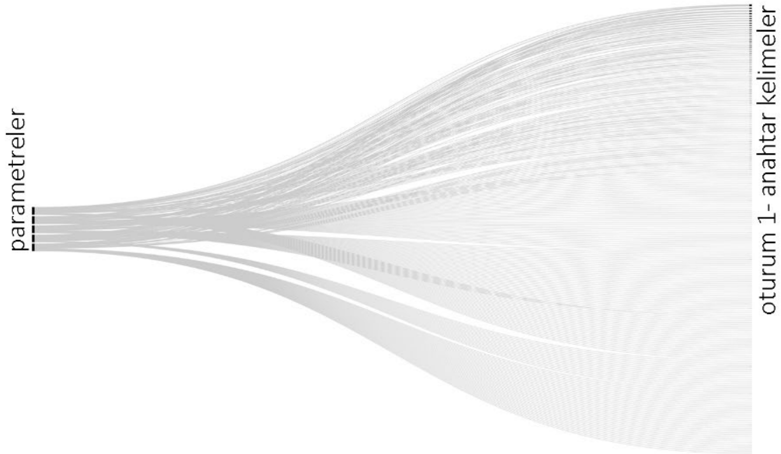
bölüm	sınıf	öğrenci sayısı	bölüm toplam	genel toplam
mimarlık	1	4	21	43
	2	4		
	3	7		
	4	6		
iç mimarlık	1	3	14	
	2	1		
	3	5		
	4	5		
gemi ve yat tasarımı	1	0	8	
	2	3		
	3	1		
	4	4		

Tablo 1: Katılımcı profilleri.
Participant profiles.

Kullanılan malzemelerin temelini oluşturan baz kısmı, Tübitak Bilim Genç'te belirtilen temel biyoplastik reçetesi esas alınarak; mısır nişastası, gliserin, sirke ve su ile üretilmiştir (Url-1). Katılımcılar bu baz kısımlara farklı oranlarda tekstil atığı, talaş veya kestane kabuğu ilave ederek ısı yoluyla doğal kompozit malzemeler oluşturmuş ve farklı dayanım ve esneklik özelliklerine sahip farklı malzemeler elde etmişlerdir. Oturum sonunda, her katılımcıdan deneyimlediği farklı malzeme içerikleri ve ürettiği malzeme alternatiflerinden birini seçmeleri; nihai malzemelerinin duyusal, anlamsal, duygusal, performatif ve potansiyel özelliklerini, her ölçüt için 3 anahtar kelime ile ifade etmeleri istenmiştir. Bu ifadeler, ikinci oturumun girdilerini oluşturmuştur (Tablo 2) (Şekil 5).

	duyusal	anlamsal	duygusal	performatif	potansiyel
	yumuşak	gökyüzü	karmaşık	gece	top
	tatlı	gezegen	güçlü	şekillendirilebilir	kılıfı
	sessiz	orkide	korku	dayanıklı	terlik
	ateş	çocukluk	özlem	sürdürülebilir	kase
	sıcak	ev	huzurlu	yenilikçi	mobilya
	sert	dinginlik	yumuşak	şekillendirilebilir	kamp
	sert	sağlam	güvenli	şekillendirilebilir	form
	homojen	konforlu	kontrollü	tutucu	kaplama
	şekil alma	yoğun	kararlı	dayanıklı	bağlayıcı

Tablo 2: Birinci oturum üretimlerinden örnekler.
Examples from first session productions.



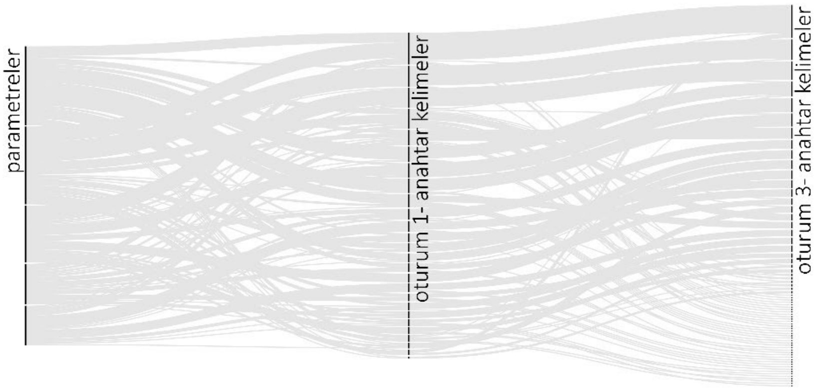
Şekil 5: Oturum 1 sonrası elde edilen anahtar kelimelerin çeşitliliği.
Diversity of the keywords gathered after first session.

İkinci oturumda, ilk gün malzeme deneyimi sonucunda üretilen kavramlardan hareketle YZ destekli tasarım ile form üretimi için, katılımcılar, Midjourney aracılığıyla, işlevsiz bir tasarım nesnesine dair çeşitli form alternatifleri geliştirmişlerdir. Bu aşamada, her bir katılımcıya Midjourney ile 5 deneme yapma olanağı verilmiştir. Denemeler sonunda katılımcılardan, malzeme özelliklerini en iyi yansıttığını düşündükleri bir denemeyi seçmeleri istenmiştir (Tablo 3).

Tablo 3: YZ destekli ve gerçek form üretimlerinden örnekler.
Examples from Aı-supported and physically produced forms

yapay zeka destekli form üretimi	malzeme ile form üretimi
	
	 
	

Son oturum, YZ destekli tasarlanan formların, biyo-polimer malzemelerle fiziksel olarak üretilmesini içermektedir. Bu oturum, 10x15x25 cm. boyutlarıyla sınırlı olarak üretilen nesneler üzerinden, malzeme ile form ilişkisinin ve etkileşiminin deneyim aracılığıyla süreçteki değişiminin ortaya konmasını hedeflemektedir. Oturum sonunda, katılımcılardan, ihtiyaç duyulan/duyulmayan malzeme revizyonları ile, tüm süreç sonunda, malzemelerine ilişkin ilk oturumda belirttikleri anahtar kelimelerdeki değişimleri tespit edebilmek adına, sonuç ürüne dair anahtar kelimelerini belirtmeleri istenmiştir (Şekil 6).



Şekil 6: Oturum 3 sonrası elde edilen anahtar kelimelerin çeşitliliği.
Diversity of the keywords gathered after third session.

İlk oturum ile son oturum sonunda elde edilen anahtar kelimelerin analizi, üretilen formların biçimsel özelliklerini tanımlayan nesnel sıfatlar ile malzemeye dayalı ilk tasarım düşüncesi arasındaki bağlantıları, değişim ve dönüşümleri ortaya koyacaktır. Bu nedenle, malzeme deneyimi, malzemenin özelliklerine dayanarak YZ ile form tasarlama, tasarlanan formu üretme aşamalarından meydana gelen çalıştay sürecinin detaylı incelemesi ilk ve son oturumlar sonunda tariflenen anahtar kelimelerin değişimi/aynılığı/yoğunluğu üzerinden yapılmıştır. Çok sayıda ve çok farklı tipte çıktıya sahip bu katmanları okumak ve aralarındaki bağlantıları açığa çıkarmak, ilişkisellik/ilişkisizlik durumunu analiz etmek için, tüm aşamaların çıktıları içerik analizi yöntemi ile sınıflandırılarak incelenmiştir.

İçerik analizi, metin ve verilerde kodlama ve temaları veya örüntüleri tanımlama sürecini sistematik olarak sınıflandırmayı içeren bir araştırma yöntemi olarak tanımlanır (Hsieh ve Shannon, 2005). İçerik analizinde, farklı araştırmacılar tarafından çeşitli terimlerle tanımlanan üç kodlama yöntemi kullanılır. Kavram odaklı (Schreier, 2012) veya doğrudan/didaktik kodlama (Hsieh ve Shannon, 2005), önceden belirlenmiş bir yaklaşım veya modele dayanır. Buna karşılık, veri odaklı (Schreier, 2012), geleneksel içerik analizi veya endüktif kodlama (Hsieh ve Shannon, 2005), parametrelerin araştırmacı tarafından önyargısız olarak belirlenmesine dayanır ve metnin analizini içerir. Üçüncü yaklaşım olan özetleyici içerik analizi (Hsieh ve Shannon, 2005), endüktif ve didaktik yöntemleri birleştirir. Temaları didaktik kodlama yoluyla oluştururken, parametrelerin endüktif kodlama yoluyla ortaya çıkmasına olanak tanır.

Bu bağlamda, malzemeyi odağına alan çalıştayın hazırlık sürecinde, parametreler önceden araştırmacılar tarafından duyusal, duygusal, algısal, performans ve potansiyel olmak üzere belirlenmekle birlikte; alt parametreler tarfilenmeyerek, katılımcıların ifade ettiği anahtar kelimeler ile oluşturulmuştur. Bu nedenle, bu araştırmanın verileri, üçüncü yaklaşım olan özetleyici içerik analizi yöntemi kullanılarak incelenmiştir.

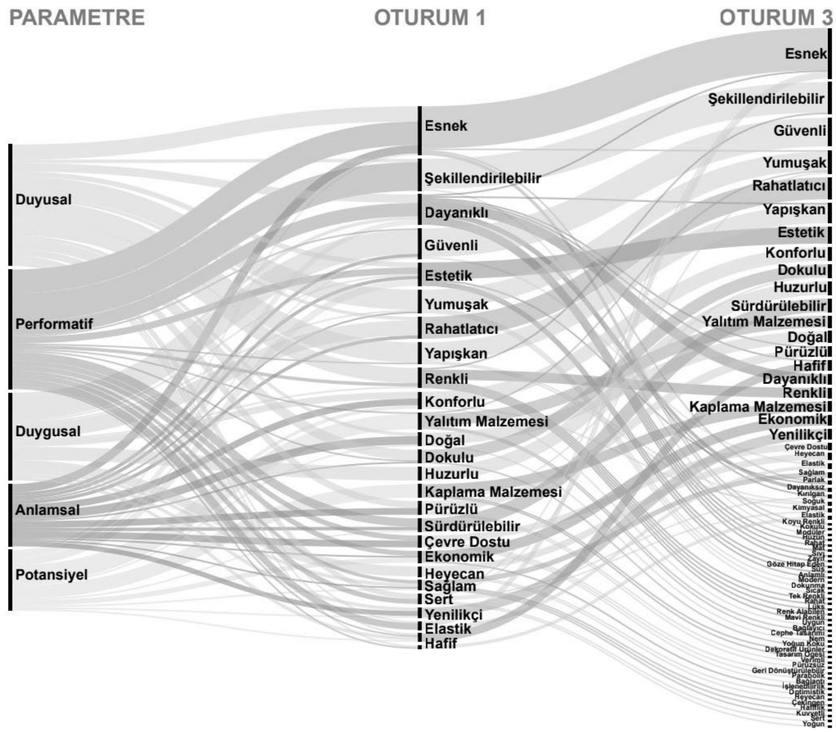
Araştırmada her parametre için üçer adet olmak üzere, her bir katılımcıdan her oturumda 15'er, katılımcı başına toplam 30, ve tüm süreç için en fazla toplam 1290 anahtar kelime elde edilmesi hedeflenmiştir. Ancak 43 katılımcıdan, her oturumda 616 olmak toplam 1232 anahtar kelime elde edilmiştir. Katılımcıların tariflediği anahtar kelimelere ilişkin veriler incelendiğinde, en fazla sayıda anahtar kelimenin duyusal parametre için (126), en az sayıda anahtar kelimenin ise potansiyel parametre için (120) yapıldığı tespit edilmiştir. Diğer taraftan, tüm parametrelere ilişkin ifadeler toplam olarak değerlendirildiğinde ise, malzeme deneyimini içeren ilk oturumda 272 anahtar kelime tariflenirken, fiziksel üretimi içeren son oturumda ise anahtar kelime sayısının artarak 281'e çıktığı görülmektedir. Anahtar kelimelerin parametrelere göre değişim oranları karşılaştırıldığında ise, en büyük değişim duyusal parametrelerde, en az değişim de duygusal parametrelerde gerçekleşmiştir (Tablo 4).

Tablo 4: Oturumlara göre anahtar kelime değişimleri
Keyword changes according to the sessions.

parametre	oturum 1 anahtar kelime	farklı kelime adet	oturum 3- değişen anahtar kelime	farklı kelime adet	değişim yüzdesi
duyusal	126		48		0.38
anlamsal	124		33		0.26
duygusal	124	272	25	281	0.20
performans	122		30		0.24
potansiyel	120		35		0.29
toplam	616		171		0.27

İlk oturum sonunda en çok belirtilen anahtar kelimeler, esnek (29), şekillendirilebilir (19), dayanıklı (18), güvenli (18), estetik (14), yumuşak (14), rahatlatıcı (13), yapışkan (13), renkli (12), konforlu (10), yalıtım malzemesi (10), doğal (8), dokulu (8), huzurlu (8), kaplama malzemesi (8), pürüzlü (8), sürdürülebilir (8), çevre dostu (7), ekonomik (7), heyecan (6), sağlam (6), sert (6), yenilikçi (6), elastik (5) ve hafif (5) olmuştur. İlk oturumda ifade edilen anahtar kelimeler ile son oturumda ifade edilen anahtar kelimeler karşılaştırıldığında ise, 60 adet kelimenin çok büyük anlamsal farklılığa sahip olacak şekilde değişikliğe uğradığı tespit edilmiştir. Bu bağlamda, en çok sayıda değişim, ilk oturumda belirtilen dayanıklılık ifadesinin son oturumda dayanıksız, hafif, kırılgan gibi karşılıklar bulması ile gözlemlenmiştir. Benzer şekilde, oturumlar arasında anlamsal zıtlığa doğru değişen diğer anahtar kelimeler, pürüzlü ifadesinin pürüzsüze, sert ifadesinin yumuşağa dönüşümü ile de görülmektedir.

Elbette, oturumlar arasındaki anahtar kelimelerin değişimi yalnızca zıtlıkları içeren tariflemeler üzerinden yapılmamıştır. Özellikle potansiyel parametresinde belirtilen yalıtım malzemesi ifadesinin bağlayıcı, cephe tasarımına ve kaplama malzemesinin dekoratif ürünlere dönüşümü, üçüncü oturumdaki fiziksel üretim süreci sonunda malzemenin potansiyellerinin daha iyi anlaşıldığına işaret etmektedir. Yalnızca bir adet değişimin görüldüğü şekillendirilebilir ifadesinin, performatif parametresi altında modülere dönüşmesi ise, form oluşturma konusunda katılımcının daha net bir kararı olduğunu göstermektedir. Duygusal parametre altındaki güvenli, rahatlatıcı, huzurlu ile performans parametre altındaki sürdürülebilir ifadelerinin hiçbir değişime uğramadan her iki oturumda da kullanılmış olması, bir başka önemli bulgudur. Tüm anahtar kelimeler incelendiğinde ise, duygusal parametrelerin en az sayıda değişime uğraması, katılımcıların kendilerinin tasarladıkları malzeme ile deneyim ve dokunma temelli kurdukları bağın, YZ destekli tasarım aşamasından biçim üretimine kadar kuvvetli bir şekilde sürdürülmesi olarak yorumlanabilir (Şekil 7).



Şekil 7: En sık kullanılan ifadelerin değişimi.
The changes in most used pharases.

Diğer taraftan, çoğu katılımcının, ilk oturumda deneyimleyerek ürettiği malzeme alternatifleri arasından karar verdiği malzeme reçetesini, ikinci oturumda YZ destekli tasarladığı formu üçüncü oturumda fiziksel olarak üretme aşamasında değiştirdiği görülmüştür. Her ne kadar malzeme reçetesi değişikliğe uğramışsa da, bu değişiklikler büyük oranda performans ve potansiyel parametrelerinde belirtilen anahtar kelimelerde gerçekleşmiş; anlamsal, duyusal ve duygusal parametrelerde belirtilen kelimelerde da sınırlı sayıda değişiklik yapılmıştır. Bu durum, katılımcıların tasarladıkları formu fiziksel olarak üretebilme adına, malzeme reçetesinde çeşitli revizyonlar yapılmasına rağmen, katılımcıların malzeme ile olan ilk etkileşimi sırasında bireylerin deneyimi aracılığıyla algısal olarak yarattığı öznel etkiyi kaybetmediğini ortaya koymaktadır.

4. SONUÇ VE TARTIŞMA (CONCLUSION AND DISCUSSION)

Bu araştırma, tasarım sürecinde form üretiminin yalnızca biçimsel ve görsel bir temsil olmaktan öte, malzeme başta olmak üzere çok sayıda algısal ve deneyimsel bileşenin bir arada ele alındığı etkileşimli bir süreçle ortaya konulduğunu göstermiştir. Çalıştay kapsamında üretilen nesneler, onu malzeme ile tasarlayan bireylerin zihninin yansımasıdır. Bu anlamsal yansımalar, salt biçime dayanan görünüş ve gerçekliklerin yanı sıra, tasarımcıların bireysel duyuları ve duyguları ile bağlantılı çağrışımları da içermektedir. Bu bağlamda, çalıştay süresince gerçekleştirilen malzeme ve YZ destekli tasarım süreci, tasarım nesnesi ile tasarımcı arasındaki etkileşim ve iletişiminin önemini ortaya koymuştur. Bu etkileşimi belirleyen en temel olgu ise, malzemenin maddesel özelliklerinden öte, tasarımcı bireylerin deneyimleri, algılama biçimleri ve kavramsal yaklaşımları olmuştur.

Bu çerçevede, çalıştay ve çalıştayda elde edilen verilen analizi, tasarımcı adaylarının aynı biyo-polimer baza eklemelerle elde ettikleri bireysel tarifleri kullanarak malzemenin duygusal, duyusal, anlamsal, performatif ve potansiyel özelliklerini belirlemeleri ve bu özelliklerin form tasarlama ve üretme sürecindeki etkili rolünü keşfetme yolundaki deneyimlerini ortaya koymuştur.

Diğer taraftan, dijitalleşmenin gündelik hayatın doğal bir parçası olduğu günümüzde tasarım eğitimindeki öğretme ve öğrenme biçimlerinin değişmesi, yeni nesil öğrenme modellerinin geliştirilmesini zorunlu kılmaktadır. Bu çerçevede, çalıştay sağladığı enformel öğrenme ortamı ve bu ortamda gerçekleştirilen deneyime dayalı bireysel üretim süreçleri ile yeni nesil YZ uygulamalarının form tasarımı sürecine entegrasyonu ile, tasarım disiplinlerinin özünde olan çeşitli ortaklıklar ve birlikteliklere dair de referanslar içermektedir.

Farklı eğitim düzeyi ve tasarım disiplinlerinden toplam 43 öğrencinin katılımı ile gerçekleştirilen bu araştırma, farklı eğitim alanları ve seviyelerinin karar verme süreçlerindeki etkisini anlamak için, gerek sürdürülen gerekse de gelecekte gerçekleştirilecek diğer çalışmalar için de önemli bir veri oluşturmaktadır. Tasarımın ölçek, malzeme, deneyim ve öğrenme biçimi gibi yaratıcılığı tetiklediği düşünülen özelliklerini birlikte alan çalışma, bu yönüyle de insan ve YZ konulu çalışmalar için de faydalı bir çerçeve önerisi ortaya koymaktadır.

Teşekkür (Acknowledgement)

Bu araştırma Maltepe Üniversitesi MÜAR tarafından desteklenmektedir. Çalışmaya katılan her katılımcıdan rıza ve onam belgeleri temin edilmiştir. Maltepe Üniversitesi'ne ve katılımcılarımıza değerli katkı ve desteklerinden dolayı teşekkür ederiz.

Çıkar Çatışması Beyanı (Conflict of Interest Statement)

Çalışma çıkar çatışması içermemektedir.

Katkı Oranı (Author Contribution)

Tüm yazarlar çalışmaya eşit oranda katkı koymuşlardır.

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Computational Design with Kurtboğaz: The Generation of Timber Structures with an Aggregative Design Algorithm

İlay Beylun Ertan[1], Pınar Çalışır Adem[2]

ORCID NO: 0000-0002-0823-41061[1], 0000-0001-6139-62892[2]

[1,2] Yeditepe University, Faculty of Architecture, Department of Architecture, İstanbul, Türkiye

This paper investigates the form-finding capacity of the traditional timber-joint construction method, Kurtboğaz, aiming to explore new architectural forms and possibilities through computational design techniques to preserve vernacular construction methods and integrate them into contemporary architecture. It presents an Aggregative Design Algorithm (ADA) that creates different structures based on designer rules and simple assembly rules of Kurtboğaz, leading to unique emergent forms through random rule application. The paper also explores how reinforcement learning, a type of machine learning, can improve this design process through a theoretical framework. The study tries to use a rule-based generative algorithm to explore the modular and reconfigurable characteristics of the Kurtboğaz. The ADA enables random rule application, leading to diverse forms. However, several challenges may be encountered during the application of ADA because of its random aggregation, such as self-collision and boundary detection. The study suggests using Reinforcement Learning (RL) in the ADA framework to address these problems. Incorporating RL is anticipated to enable the algorithm to adaptively learn and optimize the form-finding process, enhancing the performance and applicability of the Kurtboğaz method in contemporary architectural practice. In the future, with this generative process described by the study, designs that create spatial differences with the help of walls, floors, and rooms on a human scale can be realized. The study also plans to explore the synergy between craftsmanship and digital fabrication in the future.

Received: 10.07.2024
Accepted: 16.09.2024

Corresponding Author:
ilaybeylun.ertan@gmail.com

Ertan, İ.B. & Çalışır Adem, P. (2024). Computational design with Kurtboğaz: The generation of timber structures with an aggregative design algorithm, *JCoDe: Journal of Computational Design, 5*(2), 235-258. https://doi.org/10.53710/jcode.1514063

Keywords: Aggregative Design Algorithm, Traditional Architecture, Timber-Joint System, Kurtboğaz, Reinforcement Learning.

Kurtboğaz ile Hesaplamalı Tasarım: Birleştirici Tasarım Algoritması ile Ahşap Yapıların Üretimi

İlay Beylun Ertan[1], Pınar Çalışır Adem[2]

ORCID NO: 0000-0002-0823-41061[1], 0000-0001-6139-62892[2]

[1,2] Yeditepe Üniversitesi, Mimarlık Fakültesi, Mimarlık Bölümü, İstanbul, Türkiye

Bu makale, geleneksel ahşap geçme yapım yöntemi olan Kurtboğaz'ın form bulma kapasitesini araştırmakta ve bu yöntemi korumak ve çağdaş mimariye entegre etmek amacıyla hesaplamalı tasarım teknikleri aracılığıyla yeni mimari formlar ve olasılıklar keşfetmeyi hedeflemektedir. Çalışma, tasarımcı tarafından belirlenen hareket kurallarına ve Kurtboğaz'ın basit montaj kurallarına dayalı olarak farklı yapılar oluşturan ve rastgele kural uygulaması yoluyla öngörülemeyen formlar ortaya çıkaran Birleştirici Tasarım Algoritmasını sunar. Ayrıca bu çalışma, bir tür makine öğrenimi olan pekiştirmeli öğrenmenin bu tasarım sürecini teorik bir çerçevede nasıl iyileştirebileceğini araştırmaktadır. Kurtboğaz'ın modüler ve yeniden yapılandırılabilir özellikleri Kurtboğaz'ın form bulma kapasitesini incelemek için güçlü bir temel sağlamaktadır. Birleştirici Tasarım algoritması geleneksel mimariyi hesaplamalı tasarım ile yorumlamak suretiyle Kurtboğaz'ın basit yapım-montaj kuralları üzerinden sayısız kombinasyon oluşturma potansiyelini gösterir. Birleştirici Tasarım Algoritması, rastgele kural uygulamasını mümkün kılarak çeşitli biçimlerin oluşmasını sağlamaktadır. Ancak, Birleştirici Tasarım Algoritması'nın rastgele birleştirme nedeniyle uygulanmasında blokların üst üste çarpışması ya da sınırlar içinde kalma gibi çeşitli zorluklarla karşılaşılabilir. Bu zorlukların üstesinden gelmek için, bu çalışma Birleştirici Tasarım Algoritması çerçevesine Pekiştirmeli Öğrenme'nin (PÖ) teorik entegrasyonunu önermektedir. PÖ'nün entegrasyonu, algoritmanın form bulma sürecini uyarlamalı olarak öğrenmesini ve optimize etmesini sağlayarak, Kurtboğaz yönteminin performansını ve uygulanabilirliğini çağdaş mimari pratikler bağlamında artırabilir. Sonuç olarak çalışma Kurtboğaz'ın algoritmik kural tabanlı bir mantık içerisinde form bulma yeteneğini onun temel özelliklerini keşfederek incelemekte ve PÖ ile desteklenen bir tasarım süreci geliştirmektedir.

Teslim Tarihi: 10.07.2024
Kabul Tarihi: 16.09.2024

Sorumlu Yazar:
ilaybeylun.ertan@gmail.com

Ertan, İ. B. & Çalışır Adem, P. (2024). Kurtboğaz ile hesaplamalı tasarım: Birleştirici tasarım algoritması ile ahşap yapıların üretimi. *JCoDe: Journal of Computational Design, 5*(2), 235-258. https://doi.org/10.53710/jcode.1514063

Anahtar Kelimeler: Birleştirici Tasarım Algoritması, Geleneksel Mimari, Ahşap-Geçme Yapım Sistemi, Kurtboğaz, Pekiştirmeli Öğrenme

1. INTRODUCTION

Knowledge embedded in traditional architecture and construction methods persists through generations by enhancing regional expertise. This expertise, refined and passed down over time, has been tested in various conditions (Golden, 2017). However, traditional methods face challenges in the contemporary world due to the decline of master builders and the growing preference for new construction techniques. Additionaly, buildings constructed with traditional methods are vanishing due to neglect and modification. Traditional timber construction methods offer substantial potential for modularity, demountability and reconfigurability. There are many contemporary architects who get inspired by traditional architecture and use local materials and construction methods in their designs. For instance, Kengo Kuma (**Figure 1**) interpreted Japanese traditional methods of timber for his Pavilion in Paris. In the Swiss Sound Pavilion (**Figure 2**) Peter Zumthor's designs merge contemporary architecture with local materials and methods.

Figure 1: On the left: Kuma's Pavilion in Paris (Morby, 2015).
Figure 2: On the right: Zumthor's Swiss Pavilion (Juergen, 2000).

In this context, this paper integrates traditional construction methods into contemporary architecture via computational medium. Traditional construction methods have a particular set of rules to generate building elements. The study focuses on how traditional construction methods, specifically the Kurtboğaz, can produce emergent forms using computational medium. In this regard, the study presents an Aggregative Design Algorithm (ADA) which is a rule-based generative algorithm with a combinatorial logic, to study form-finding capacity of the Kurtboğaz. The Kurtboğaz has modular and reconfigurable properties and a potential for generating many combinations with simple assembly rules. Thus, for the form-finding algorithm ADA, one of the timber-joint system, Kurtboğaz was selected as a design case. Since ADA works with a combinatorial logic and depended on the geometric calculations decided by the designer, different polyhedral geometries that are finite and discrete may be also used in this algorithm. In this context, the methodology of the study can be followed in **Figure 3.**

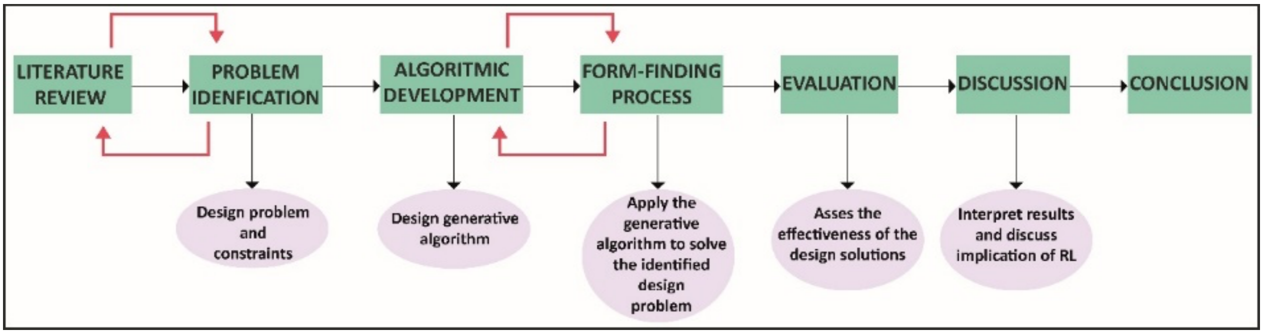


Figure 3: The methodology of the study.

2. COMPUTATIONAL TIMBER

Traditional architecture, which integrates natural elements, forms, and materials, can be an important model for modern architectural practices. Current approaches that engage with traditional architecture seek to understand and incorporate local values and experiences into contemporary designs. This approach actively values and preserves landscape and structural heritage. Innovative designs can be realized using existing technology, skills, and structures (Creangă et al., 2010).

While wood is one of the oldest construction materials, recent innovations in production techniques and design tools have introduced new formal, aesthetic, and structural possibilities, expanding its range of applications (Bianconi and Filippucci, 2019).

There are various studies which digital and parametrical models were used to control the geometry, assess the structural design, and help the management of wooden pieces’ production, classification, and assembly. Digitalize the process means to gain a better control over each phase and procedures, transferring the earlier ideas and sketches into an engineered knowledge (Kuma et al., 2019).

For instance, Kuma et al. (2019) introduced KODAMA, a sophisticated wooden structure that forms a "porous sphere" (a polyhedron) constructed from a single type of wood section, assembled without the use of nails or screws. The design, development, and construction processes were iterative, involving a balance of theoretical validation and computational experimentation to optimize the wooden elements, their dimensions, the choice of material, the connections, and, ultimately, the mechanical performance and overall impact of the structure. The wooden façade of the Japan Pavilion at EXPO Milano 2015- Wooden Byobu, designed by Atsushi Kitagawara Architects, exemplifies a digitally crafted wood structure assembled without screws or nails, utilizing a "compressive-tension" effect. This concept draws inspiration from traditional Japanese woodworking techniques and the craftsmanship of intricate wooden toys. The design process reimagines the tradition of Japanese wooden construction, exploring geometries, spatiality, and the interplay of light and shadow, starting from small-scale physical models (Kitagawara et al., 2019).

A comprehensive review by Ottenhaus et al. (2023) presents studies on design principles that promote adaptability in timber buildings through design for disassembly and reuse. They also examine reversible timber connection systems that facilitate adaptability and disassembly. Hua et al. (2022) points out the knowledge embedded in the old modular structures and gets inspired by the East Asian timber architecture to produce re-configurable, modular timber frame with a scheme for re-using of timber elemets for another structure. Adel et al. (2018) concentrate on methods for designing non-standard timber frame structures, facilitated through united multi-robotic fabrication at the building scale. Österlund and Wikar (2019) presents various case studies representing non-linear, fluid timber structures with their compution and fabrication processes. Retsin (2019, p.8), introduces discrete architecture and “computational parts” along with the physical, material and economic features of this paradigm. Although discrete architecture does not specifically focus on timber structures, the logic of traditional timber interlocking structures to create a whole from parts can highlight discrete architecture to digitise traditional timber structures. Xu et al. (2023) explores computational design and the shape grammars to create flexible timber architecture with Mortise-tenon joints, re-imagining Chinese timber frames for modern architecture.

This study focuses on traditional timber-joint method, Kurtboğaz, which we see instances of in Turkey's traditional architecture and tries to compute the features of this joint system to produce various spatial volumes for modern architecture. By focusing on a local and disappearing case, the study tries to mould it into a discrete design system. In this regard, this study, especially inspired by the works of KODAMA (Kuma et al., 2019) and Wooden Byobu (Kitagawara et al., 2019), aims to produce complex geometries from discrete simple parts of Kurtboğaz, while trying to create an open algorithmic flow in which machine learning can be integrated in the future, trying to control geometry with computational tools in wooden architecture and trying to contribute to the literature in search of emergent forms.

3. THE KURTBOĞAZ

In the Eastern and Central Black Sea Region, geographical conditions have necessitated the development of construction technology based on local materials (Akbaş, 2019). The primary building material in the region is wood. Wooden masonry structures can be easily dismantled and reassembled in another location if needed (Tuna, 2008). The wooden construction culture has been passed down through generations via the master-apprentice relationship (Akbaş, 2019). The wooden masonry structures in the region can be made directly from logs or from logs that have been processed into lumber. These structures are assembled by fitting the wood together at specially prepared joints at the corners. The notches prepared at the corners to tightly hold the wood together are called "boğaz." The process of stacking wooden blocks on top of each other to align with these notches is known as "geçme." The wooden pieces that are joined together at these joints do not come apart (Tuna, 2008). In these wooden masonry structures, which are anchored to the ground using different foundational techniques, the walls constructed by stacking wood on top of each other are load-bearing (Akbaş, 2019). According to Tuna (2008), there are different names for the jointing methods depending on the physical dimensions and craftsmanship of the wooden block used:

Karaboğaz: This jointing method uses wood in log form.
Kurtboğaz: In this method, the logs that will form the solid walls are processed into smooth lumber, and the joints are crafted precisely and uniformly. Since the interlocking process is done correctly in the Kurtboğaz method, there are no gaps in the wall, and no plastering is

required. This method, commonly seen in the Black Sea Region, is utilized in the "wooden masonry wall" system (Akbaş and Özcan, 2008).
Çalmaboğaz: When wooden blocks are not of the desired size, shorter pieces are joined together with the help of posts. The Çalmaboğaz technique is mostly used for partitioning interior spaces (Orhan and Çavuş, 2019).

In this study, the Kurtboğaz method, which is frequently used in the local wooden masonry architecture of the Black Sea Region, is chosen. It is more sophisticated than the Karaboğaz method, more suitable for single-piece construction and scaling than the Çalmaboğaz method, and simpler than other jointing methods (such as mortise-and-tenon). It requires no plastering and leaves no gaps on the façade. The study will explore the potential of this method to produce different forms through a more minimal interpretation, leveraging its nature of being constructed by stacking layers.

To summarize, Kurtboğaz is a technique can be seen in traditional Turkish timber craftsmanship where building elements are interlocked into eachother in a specific way without nails. Interlocking system without nails and the form of the timber elements make Kurtboğaz adaptable, easily assembled and disassembled. Thus, Kurtboğaz is a modular construction method and facilitates the reuse or recycling of materials by allowing easily disassembly and separation of the building elements. Kurtboğaz may be applied in different contexts due to its modularity and the elements of the system can be reused without extensive demolition and reconstruction. This study tries to use the Kurtboğaz method to produce integrated building elements and enclose a single-volumetric space. ADA has a system where structural elements are created by stacking or layering components on top of each other. Therefore, it is suitable for the design of masonry structures. The modular nature and stacked construction method of Kurtboğaz make it well-suited for ADA.

Figure 4: Kurtboğaz detail of an ambar (Özgüner, 2018).

The Kurtboğaz is used on the walls of the ambar, houses, mosques and watermills (**Figure 4**). There are different dimensions about the construction of Kurtboğaz in the literature. While the thickness of the wood to be used varies between 2-10 cm, the protrusion distances of the wooden pieces from the corner points vary between 15-50 cm (Özgüner, 2018; Sözen and Eruzun, 1992; Akbaş, 2015). Additionally, Akbaş (2015) states that if there is a gap of 1.5 cm at the joints, we can ensure the the system's strength.

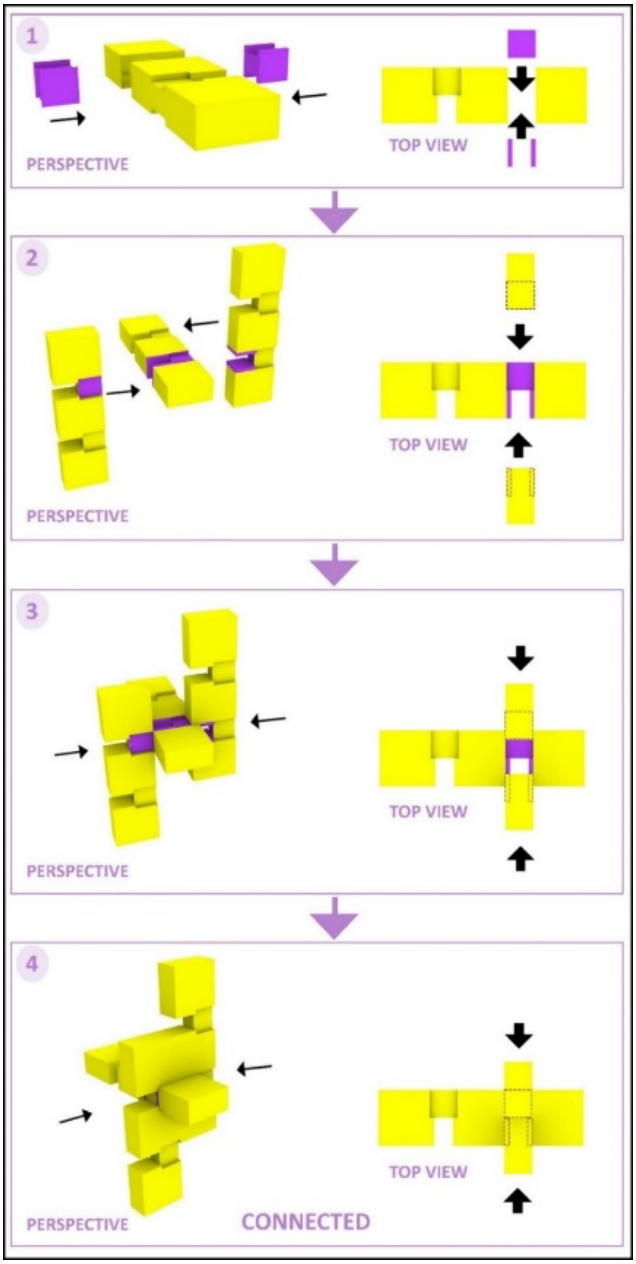


Figure 5: Connection mechanism of Kurtboğaz.

The study develops its building blocks by incorporating reference measurements. It designs building blocks that are 18 cm wide, 66 cm long, and 9 cm thick. The blocks are half-filled and half-empty at the joints, with four joint connections featuring two half-filled and two half-empty points. The half-empty parts merge with the half-filled parts, creating a more secure lock due to the 1.5 cm gaps in the filled sections. These dimensions become important when defining connection points and movement rules, as they determine how much the blocks can be moved. When different dimensions are applied, the movement rules should be adjusted according to the new dimensions (see other trials). The study designs and models these Kurtboğaz building blocks using Rhino software (**Figure 5**).

3. AGGREGATIVE DESIGN ALGORITHM FOR KURTBOĞAZ

In this paper, a selected traditional timber-joint construction method, the Kurtboğaz, will be reinterpreted in a rule-based generative computational process, which is called the Aggregative Design Algorithm (ADA), to produce a variety of architectural forms. ADA exhibits properties of infinite, fluid, and diffuse growth, capable of working with finite and discrete geometric volumes.

The development of the algorithm is empirical, involving numerous trials and experiments to organize the algorithmic flow. The authors benefit from the recursive function techniques of the Plethora Project's (Url-2) and Danil Nagy's (Url-3) code. In addition, the authors overview approaches of Danil Nagy's (Url-3) and Jake Hebbert's (Url-4, Url-5) code for using the Random module. However, ADA integrates knowledge from these references with its techniques to offer a novel solution for Kurtboğaz. The designer determines the types of connections and action rules based on the geometric volume's structure and its aggregation method. ADA randomly selects a connection type and an action rule in each iteration, resulting in different and unique combinations. These selections are made through a recursive function, causing the number of geometric volumes to increase with each iteration.

Aggregate Design Algorithm (ADA) is a Python-based class structure. There are various platforms for architects to create modular aggregations of discrete units, such as WASP (Rossi and Tessman, 2017) and Monoceros (Url-1). Monoceros utilizes Wave Function Collapse algorithm to generate wholes from smaller units and WASP uses iterative user-defined rules for geometric operations to create assemblies. The ADA got inspired WASP, but it is specifically designed for design explorations of simple timber-joint systems, such as Kurtboğaz. It is a custom algorithmic process that tries to compute a construction technique that is based on manual labour and manpower. Since the rules of Kurtboğaz, user-defined connection rules and geometric calculations are printed as an output, the working system of ADA is very open and easy to grasp. Because of printing the outputs of the design process, it is also suitable for reinforcement learning reward-punishment calculations. In the future studies, the authors will try to integrage reinforcement learning into this process.

The study develops the ADA using the GhPython component in Rhino/Grasshopper (**Figure 8**). The study begins by defining the input values of the GhPython component for ADA. The first one is the geometric volume "blockdouble" selected by the designer. For this study, the geometric volume is a four-joint kurtboğaz building block, but ADA is an algorithm that can work with more than one geometric volume. Second, it defines "numbers_of_ConnectionTypes" to control the number of connection types. This input value is the number of iterations set by the designer. As the number value changes, the number of building blocks of the aggregation increases or decreases. Finally, the study defines "seed" to create a different aggregation combination for each number change. In this input value, each "seed" number value represents a different aggregation combination. (**Figure 6**).

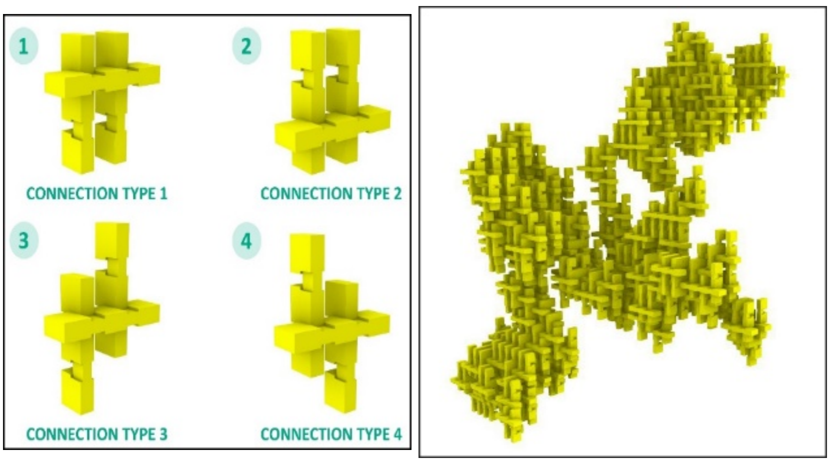


Figure 6: On the left: The connection types designed by the authors; on the right: a large aggregation.

In the pseudocode of ADA (**Figure 7**), *The Aggregative* class starts with basic functions to handle surfaces (e.g., exploding surfaces, getting centroids, duplicating borders). *FromCopytoOrient* function handles the creation and orientation of copies of Kurtboğaz blocks based on certain surface indices, which are passed as arguments. *LoopAggregation* is a recursive function which aggregates the Kurtboğaz blocks defined by connection types, applies transformations, and updates the brep list. It uses a combination of copying, orienting, and moving objects in 3D space. Finally, the *Main Execution* initializes variables, creates an instance of *Aggregative*, and processes the *LoopAggregation* to form the final output.

Figure 7: The pseuduocode of ADA.

```
import rhinoscriptsyntax, random
class Aggregative():
   Initialize with an optional general_rules_list
   Function explodeSurface(brep):
      Explode brep into PolySrf
      Return PolySrf
   Function centerPoint (brep):
      Get the surface at given index from explodeSurface(brep)
      Get the centroid of the surface
      Return the centroid point
   Function surfaceBorderLines (brep):
      Get the surface at given index from explodeSurface(brep)
      Duplicate its border and explode into curves
      Return the relevant curve
   Function midPoint(index, brep):
      Get the curve from surfaceBorderLines(brep)
      Get and return the midpoint of the curve
   Function onlyCopy(brep):
      Copy the brep object
      Return the copied object
   Function fromCopytoOrient(brep, index_pairs):
      Initialize an empty list
      For each pair of indices in index_pairs:
         Get the center point and midpoint for each index
         Store the points in a list
      Create a copy of brep
      Orient copies using these point pairs
      Append the copies and oriented objects to the list
      Return the list
   Function loopAggregation(brep, brepList, repeated_number, number_x, number_y, number_z):
      If repeated_number > 0:
         Set vector to (number_x, number_y, number_z)#determines the rules for moving
         Create and move geometry objects from multiple `fromCopytoOrient` calls
         Store these geometries in rulesGeometry
         Select a random geometry and update brepList
         Determine next move based on a random action value
         Print rulesGeometryList and rulesMovingList
         Recursively call loopAggregation with updated parameters
Main Execution:
   Initialize blockList and position variables
   Seed the random generator
   Create an Aggregative instance
   Call loopAggregation and append result to blockList
   Extract general rules into ListConnectionTypesNames and ListActionRules from general_rules_list
```

ADA can be applied to all finite and discrete geometric volumes. It iteratively aggregates geometric volumes by performing the required computations. The study evaluates ADA in three stages. The first one is the formal calculation of geometric volumes to create connection types. The designer determines the appropriate surfaces, the necessary edges and points of these surfaces with the help of ADA to create connection types according to the characteristics of the geometric volumes. ADA manipulates the geometric volumes with these descriptions. This study performs these operations on a single Kurtboğaz building block. The second stage is the creation of connection types. In this stage, the designer decides on the various connection types of the geometric volumes with different orientation actions, which is done by ADA's connection type generation method. This study has four connection types for the Kurtboğaz building block. The final stage is the iteration and aggregation of the geometric volumes. At this stage, ADA uses a function method that calls itself. This method contains the previously defined connection types and the action rules that allow movement in the designer's x, y, and z directions. In the study, for the Kurtboğaz building block, the designer decides the action rules to eight. The method randomly selects a new connection type and action rule at each iteration. In this study, each random selection adds three Kurtboğaz building blocks to the aggregation. This process results in aggregation blocks.

3.1 Form Generations without a Boundary

Each unique ADA seed value produces a distinct combination of randomly selected connection types and action rules. In the initial experiment, the study aims to compare these Kurtboğaz structures to illustrate their differences. By changing the seed value, various combinations of connection types and action rules are tested **(Figure 9)**. The study also investigates the generation potential of ADA with different geometric volumes. The second experiment uses a standard geometric volume, the cube. The third experiment tests a different timber joint method, mortise and tenon. In both experiments, the study makes one hundred generations with seed values from one to one hundred and evaluates ten of these one hundred generations. The results show that, similar to the Kurtboğaz building block, ADA can create different combinations with different seed values by making random selections. The ability to generate similar outcomes using both a standard geometric volume and a different timber joint method, as interpreted by a designer, demonstrates that ADA can work harmoniously with finite and discrete geometric volumes.

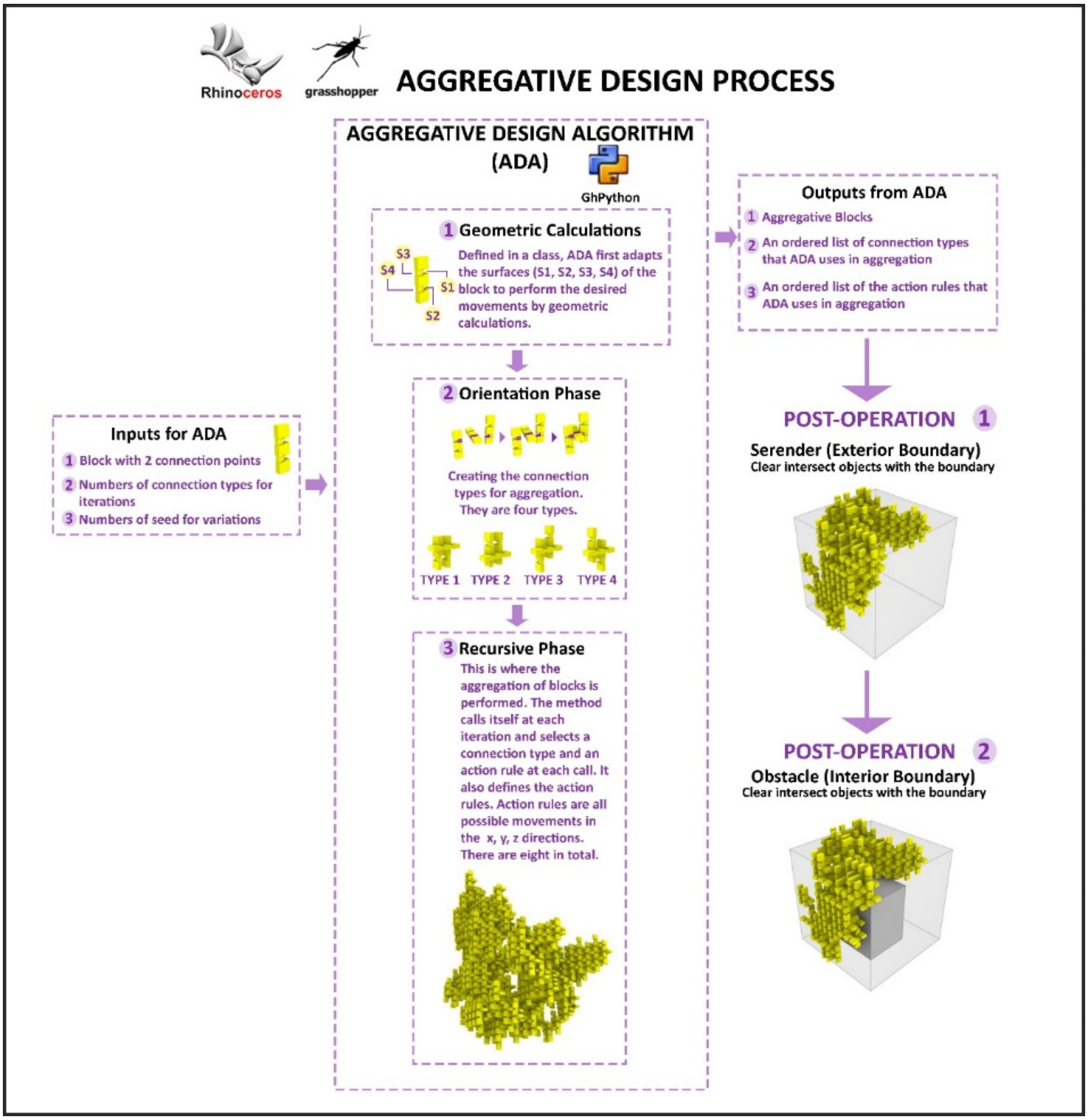


Figure 8: Aggregative Design Process

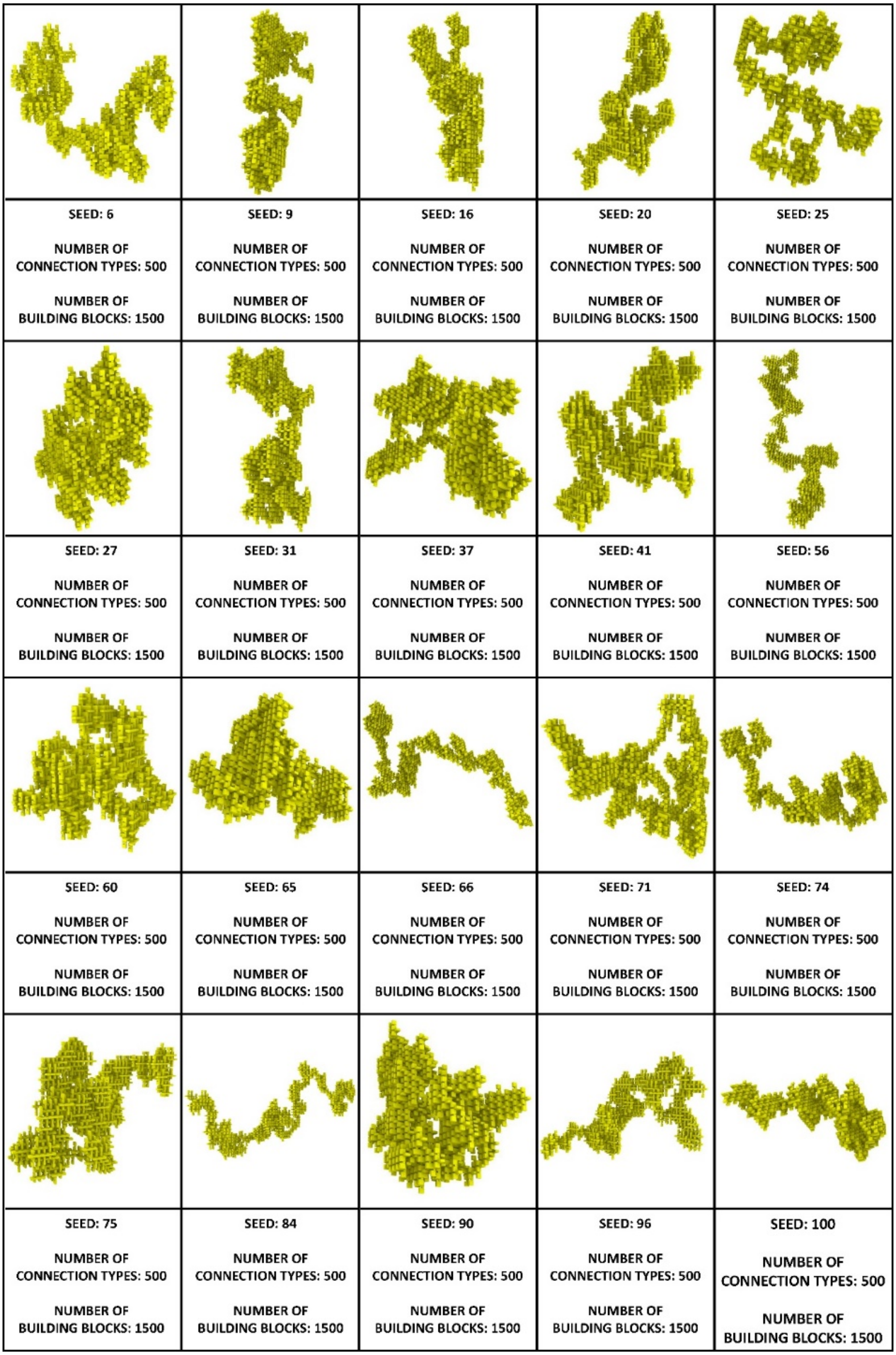
3.2 Form Generations within a Boundary

In this experiment, the operation of the ADA within certain volumetric boundaries was tested. The study shows the effect of each different number of ADA seed values on the form-finding process and tries seed values from one to one hundred (**Figure 10**, top). It uses a total of five different exterior and interior boundaries (**Figure 10**). In the various experiments with different geometric volumes, ADA randomly selects connection types and action rules at each iteration, completing all experiments in five hundred iterations. In the Grasshopper algorithm, the study operates various post-operations for ADA to fit aggregated forms within certain volumetric boundaries. In another experiment

(**Figure 10**, bottom), the authors present the five examples of the seed value:90. The number of connection types are "50", "100", "150", "200", "250", "300", "350", "400", "450" and "500". The counterparts of these numbers in terms of building block numbers are "150", "300", "450", "600", "750", "900", "1050", "1200", "1350" and "1500". The randomly aggregated forms generated by ADA fit within certain boundaries by geometric post-operations performed in the Grasshopper. Since ADA chooses connection types and action rules randomly and geometric boundaries are fixed in this random growth, volumetric boundaries may not always cover adequate building blocks. As the authors will mention in the discussion section, this issue can be solved by adjustments to the Grasshopper interface or the random selection nature of ADA. However, in this study, a theoretical framework with RL is discussed to solve the aggregation issue within a given boundary.

To sum, ADA can generate an infinite and unorganized generative process using Kurtboğaz building blocks, with each aggregated form being unique. While some generations undergo a highly disorganized diffusion process, others follow a cumulative one. The study also explores the form-finding process with ADA for various exterior and interior boundaries. Due to ADA's random selection, it is challenging to use the building blocks efficiently within certain boundaries, often leading to many blocks aggregating outside the exterior boundary and thus not participating in the form-finding process. Additionally, the generated forms may encounter collisions, self-intersections, or assembly problems. The results indicate that, despite different exterior and interior boundaries, similar patterns of increases and decreases in the number of building blocks are observed every fifty iterations.

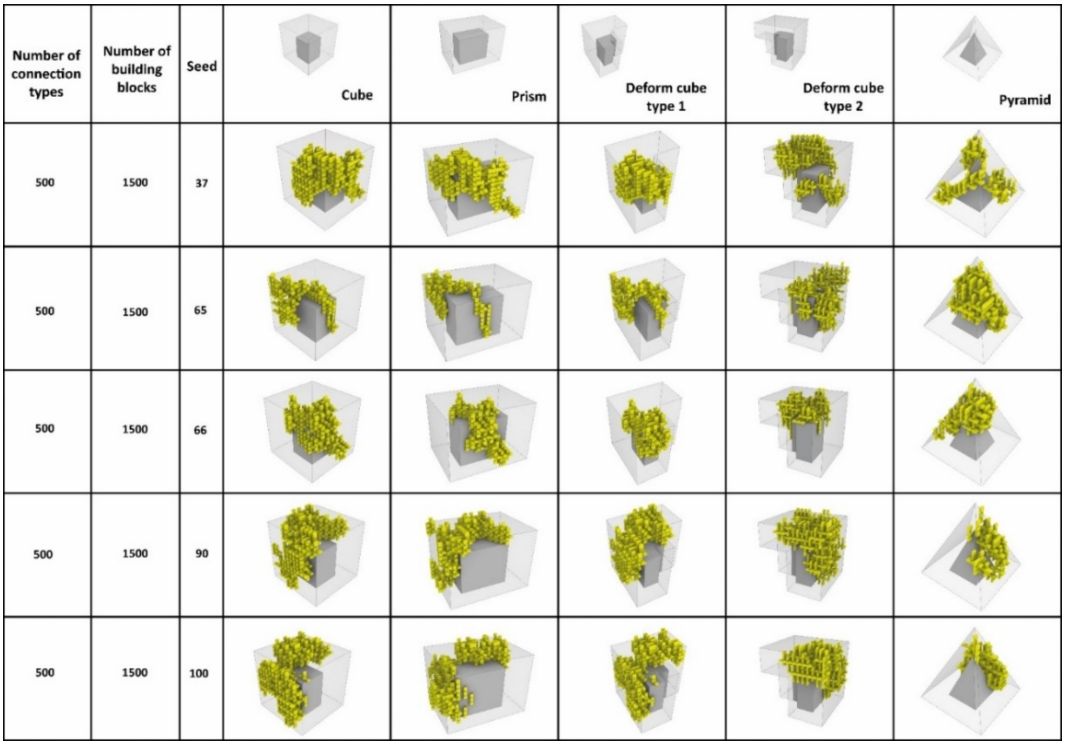
Figure 9: ADA generations without booundary.


SEED: 6
NUMBER OF CONNECTION TYPES: 500
NUMBER OF BUILDING BLOCKS: 1500
SEED: 9
NUMBER OF CONNECTION TYPES: 500
NUMBER OF BUILDING BLOCKS: 1500
SEED: 16
NUMBER OF CONNECTION TYPES: 500
NUMBER OF BUILDING BLOCKS: 1500
SEED: 20
NUMBER OF CONNECTION TYPES: 500
NUMBER OF BUILDING BLOCKS: 1500
SEED: 25
NUMBER OF CONNECTION TYPES: 500
NUMBER OF BUILDING BLOCKS: 1500
SEED: 27
NUMBER OF CONNECTION TYPES: 500
NUMBER OF BUILDING BLOCKS: 1500
SEED: 31
NUMBER OF CONNECTION TYPES: 500
NUMBER OF BUILDING BLOCKS: 1500
SEED: 37
NUMBER OF CONNECTION TYPES: 500
NUMBER OF BUILDING BLOCKS: 1500
SEED: 41
NUMBER OF CONNECTION TYPES: 500
NUMBER OF BUILDING BLOCKS: 1500
SEED: 56
NUMBER OF CONNECTION TYPES: 500
NUMBER OF BUILDING BLOCKS: 1500
SEED: 60
NUMBER OF CONNECTION TYPES: 500
NUMBER OF BUILDING BLOCKS: 1500
SEED: 65
NUMBER OF CONNECTION TYPES: 500
NUMBER OF BUILDING BLOCKS: 1500
SEED: 66
NUMBER OF CONNECTION TYPES: 500
NUMBER OF BUILDING BLOCKS: 1500
SEED: 71
NUMBER OF CONNECTION TYPES: 500
NUMBER OF BUILDING BLOCKS: 1500
SEED: 74
NUMBER OF CONNECTION TYPES: 500
NUMBER OF BUILDING BLOCKS: 1500
SEED: 75
NUMBER OF CONNECTION TYPES: 500
NUMBER OF BUILDING BLOCKS: 1500
SEED: 84
NUMBER OF CONNECTION TYPES: 500
NUMBER OF BUILDING BLOCKS: 1500
SEED: 90
NUMBER OF CONNECTION TYPES: 500
NUMBER OF BUILDING BLOCKS: 1500
SEED: 96
NUMBER OF CONNECTION TYPES: 500
NUMBER OF BUILDING BLOCKS: 1500
SEED: 100
NUMBER OF CONNECTION TYPES: 500
NUMBER OF BUILDING BLOCKS: 1500

4. DISCUSSION

In the process of ADA's generations, designer defines the connection types and action rules, and ADA randomly chooses these two main parameters. Thus, ADA's randomization of connection types and action rules leads to infinite and unorganized generations. Self collision and the number of parts to form a space within the specified boundaries (usable block number) are two of the important problems of efficiency. In form generation processes where boundaries are not defined (**Figure 9**), it was calculated that 25-45% of the parts in the resulting aggregative forms self-collided. The self-collision rates in parts with seed numbers 56, 71, and 84 are lower compared to the others. While there is vertical and linear growth in seed 56, there is horizontal and linear growth in seed 84. In seed 71, linear growth occurs in four directions: left, right, up, and down. In similar forms like seed 9 and seed 16, it is observed that in formations where the direction of linear and form flow changes, such as in seed 9, the number of repeating parts is lower.

When specific internal and external boundaries are introduced in form generation to achieve spatial differentiation (**Figure 10**, top and bottom), the issue of unused parts remaining outside the boundaries arises. When different combinations are produced with different seed numbers to examine the percentages of unusable building blocks outside the exterior boundary (**Figure 10**, top), it was calculated that 40-80% of the parts remain outside the exterior boundary in cube-prism and deformed cube 1 and 2. This rate increases in pyramid forms that narrow in a specific direction. Looking at the increasing number of parts within the same seed number, it was also calculated that more parts remain outside the boundary in the pyramid compared to other spatial limits (**Figure 10**, bottom). When looking at the number of parts used to enclose the space and serve as the shell of the volume, no significant difference was observed among the various formal boundaries, although it was slightly lower in the pyramid form. These problems in ADA can cause weaknesses in ensuring spatial closure or in the structural integrity of the form. These issues can be resolved by imposing constraints on ADA's random rule selections. However, in this study, instead of solving these problems through adjustments in the algorithm, to solve these challenges, the study offers the theoretical framework of Reinforcement Learning (RL)-supported ADA. The RL-supported aspect is the second phase of this study and will be implemented in future research.



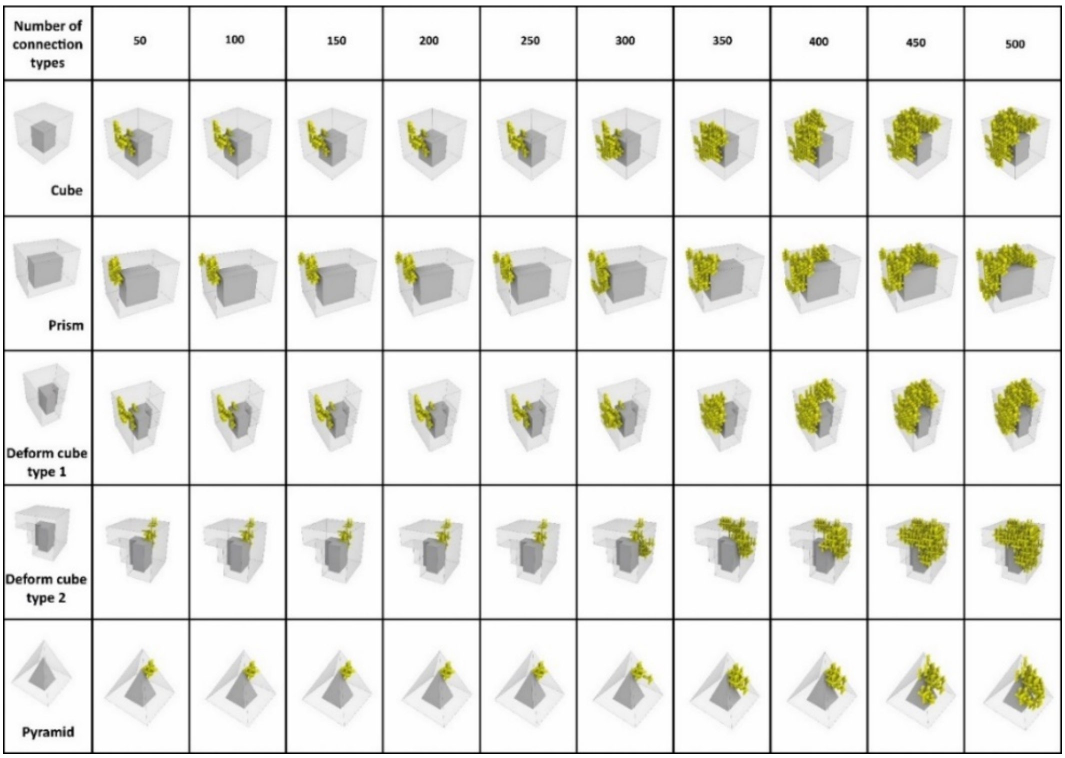


Figure 10: On the top: different seed value generations within different boundaries; on the bottom: increasing number of blocks within the same seed value.

Several form-finding trials demonstrate that ADA has significant potential to generate diverse combinations by randomly selecting connection types and action rules. However, because of the random aggregative process, the ADA process encounters design issues such as self-collision. Additionally, while the study conducts form-finding processes with the Kurtboğaz building block within boundaries, ADA's infinite and unorganized nature due to its random selections prevents the efficient use of the building blocks. To address these problems, designers can intervene to the process in several ways. For instance, they can modify ADA by evaluating and editing the generated forms, such as by making manual additions and deletions. Adding checking algorithms to detect and correct self-collision issues can also be effective. Optimization methods can be tested for boundary detection, and alternative design scenarios can be created to handle collisions and adjust generations accordingly. Additionally, structural issues can be addressed by testing with structural analysis tools. On the other hand, the machine learning (ML) algorithms, which have been included in Generative Design (GD) in recent years, can help the designer and maximize the generative potential of ADA. This study proposes a theoretical framework for supporting ADA with reinforcement learning (RL) algorithms, one of the ML methods.

In parallel with the rapid developments in machine learning, the integration of reinforcement learning algorithms into generative design has also accelerated. Wang and Snooks (2021) aim to exploit the generative potential of reinforcement learning by interpreting the spatial and structural system of Le Corbusier's Domino in a new form using a Random Walk model. In their three-dimensional study, Lye and Andrasek (2021) suggest using reinforcement learning algorithms to find complex and high-performance combinations of connection states of discrete components. Huang (2021) tries to combine complex geometries with reinforcement learning. The three-dimensional study uses waste plastic chips. Wibranek et al. (2021) focus on the problem of finding the arrangement of blocks in a sequence that can relate to different combinations. The study arranges the sequence along a given curve and utilizes SL Blocks. Reinforcement Learning-based generative models can work in 2-dimensions and develop plans or elevation proposals.

In the future studies, this paper aims to achieve three objectives by offering a Reinforcement Learning (RL)-supported framework**.** First, it seeks to produce optimal results using the identified outer and interior boundaries. Second, it aims to address the issues caused by the Aggregative Design Algorithm's (ADA) random selection of connection types and action rules. Third, it intends to integrate an autonomous design process into generative design by leveraging RL's intelligent, intuitive, and predictive nature. The RL-supported framework can enhance ADA's capabilities through autonomous processes and solve its design problems by evaluating observations and selecting the best actions. Accordingly, the framework can conduct the form-finding process with ADA within set boundaries using rewards and punishments and correctly aggregating building blocks.

5. CONCLUSION

This study evaluates the traditional timber joint method, Kurtboğaz, using computational tools to link traditional and contemporary architecture. By examining the Kurtboğaz's key features and presenting its form-finding capabilities within an algorithmic rule-based logic, the paper develops a generative design process enhanced by machine learning theoretically.

While several trials have shown ADA's ability to generate diverse aggragations through random selections, they have also highlighted design issues such as self-collision. Additionally, ADA's infinite and unorganized nature has led to inefficient use of building blocks within set boundaries. To address these, in the future studies, the study proposes evaluating ADA within a theoretical framework supported by reinforcement learning (RL) algorithms. The RL-supported theoretical framework has three objectives: first, to achieve an efficient form-finding process within defined external and internal boundaries; second, to resolve ADA's inherent design issues; and third, to establish an autonomous generative process that aids the designer.

The study outlines how RL can theoretically support this generative process to create a more autonomous and optimized system. It holistically integrates building parts with the Kurtboğaz construction method, exploring its potential as a modular and contemporary approach. By describing this traditional method within an RL-supported autonomous framework, the study combines historical knowledge with computational design tools to develop contemporary and sustainable architectural solutions, preserving traditional construction methods while fostering emergent forms.

Conflict of Interest Statement

The manuscript sent has not been presented at any meeting before. The manuscript is entitled "Computational Design with Kurtboğaz: The Generation of Timber Structures with an Aggregative Design Algorithm" has not been published elsewhere and that it has not been submitted simultaneously for publication elsewhere.

Author Contribution

This study is based on the master thesis entitled " THE GENERATION OF TIMBER-JOINT STRUCTURES WITH AN AGGREGATIVE DESIGN ALGORITHM" by İlay Beylun Ertan under the supervision of Assist. Prof. Dr. Pınar Çalışır Adem (Yeditepe University Graduate School of Natural and Applied Sciences, Dept. of Architecture, Istanbul, Turkey, 2024). The second author contributed as a guiding and supervising expert in the scientific and editorial process of the paper. The computational work and algorithms in the paper were implemented and analysed by the first author.

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Assessment of an Agent's Wayfinding of the Urban Environment Through Reinforcement Learning

Mahad Mohamed Elhadi Imhemed[1], Can Uzun[2]

ORCID NO: 0009-0007-8697-1535[1], 0000-0002-4373-9732[2]

[1,2] Altınbaş University, Graduate School of Science and Engineering, Department of Architecture, Istanbul, Türkiye.

This simulation study explores wayfinding motivated behavioral patterns in the city through agent-based modelling. Agents were trained using Unity's ML-Agents toolkit with reinforcement learning. The study uses the Sultan Ahmet Mosque and its surrounding boundary as a model environment for the training of an agent's wayfinding. Agents are trained to locate the Sultan Ahmet Mosque target. The behaviors of agents trained with two different methods, "Complex" and "Simple" learning, comparing their navigation quests at various difficulty levels featuring respawn points. After the training of the agents, the alternative routes produced while attaining the target during the wayfinding process were analyzed. As an outcome of the analysis, it was observed that the agents were prone to go off-route, navigate to different locations they perceived in the urban space, and then would reach the target. This occurrence is justified as an agent's curiosity trained through reinforcement learning. This study differs from the literature in a way that it attempts to understand the navigational behavior of agents that were trained with reinforcement learning. Moreover, this research discusses the perception of wayfinding through curiosity and aims to make a comprehension of the perception of the city, which is one of the key ideas in neurourbanism. The study contributes to the literature by showing that wayfinding behaviors acquired from agents' curiosity-driven explorations and past experiences can be an input for neurourbanism, supporting urban design. It informs urban enhancements that are user-centric and rich in urban perception using the reinforcement learning method.

Received: 08.07.2024
Accepted: 25.08.2024

Corresponding Author:
mahad.asdera@gmail.com

Imhemed, M. M. E., & Uzun, C. (2024). Assessment of an agent's wayfinding of the urban environment through reinforcement learning. *JCoDe: Journal of Computational Design and Engineering*, 5(1), 259-278.
https://doi.org/10.53710/jcode.1512798

Keywords: Behavioral Patterns, Motivational Curiosity, Neurourbanism, Reinforcement Learning, Urban Design.

Pekiştirmeli Öğrenme Yoluyla Bir Etmenin Kentsel Çevrede Yol Bulma Değerlendirilmesi

Mahad Mohamed Elhadi Imhemed[1], Can Uzun[2]

ORCID NO: 0009-0007-8697-1535[1], 0000-0002-4373-9732[2]

[1,2] Altınbaş Üniversitesi, Fen ve Mühendislik Enstitüsü, Mimarlık Bölümü, İstanbul, Türkiye.

Bu çalışma kentte yön bulma odağındaki davranış kalıplarını etmen tabanlı model üzerinden analiz eder. Çalışmanın hedefinde pekiştirmeli öğrenme ile yön bulmayı öğrenen etmenlerin davranışlarını anlamak bulunmaktadır. Çalışmanın hedefi doğrultusunda kullanılan yöntem etmen tabanlı modelleme olmuştur. Etmenler pekiştirmeli öğrenme ile Unity ML-Agents kullanılarak eğitilmiştir. Çalışma Sultan Ahmet Camii ve çevresini etmenin eğitimi için örnek bir çevre olarak almaktadır. Etmenler Sultan Ahmet Camii'yi bulmak hedefinde eğitilmiştir. Karmaşık ve basit öğrenme olarak iki farklı yöntemle eğitilen ve farklı başlangıç noktalarında yön bulma görevlerine başlatılan etmenlerin davranışları karşılaştırılmıştır. Bu çalışma pekiştirmeli öğrenme ile eğitilen etmenlerin yön bulma davranışlarını anlamaya çalışması bakımından literatürden farklılaşmaktadır. Bir diğer yönden bu araştırma yön bulma algısını merak kavramı üzerinden tartışmakta ve nöro-şehircilikte önemli kavramlardan olan kent algısını etmenler üzerinden anlamaya çalışmaktadır. Etmenlerin eğitilmesi sonrasında etmenlerin yön bulma sürecinde hedefe ulaşırken ürettikleri alternatif güzergahlar analiz edilmiştir. Analiz sonucunda, etmenlerin güzergah dışına çıkarak, kentsel mekanda algıladığı farklı konumlarda gezebildiği ve sonrasında hedefe ulaştığı görülmüştür. Bu durum pekiştirmeli öğrenme ile eğitilen etmenin merakı olarak açıklanmıştır. Etmenlerin merak odaklı keşiflerinden ve geçmiş deneyimlerden elde edilen yön bulma davranışları, kentsel tasarımı destekleyecek n nöro-şehirciliğin bir girdisi olabilmesi yönünde çalışma literatüre katkıda bulunmaktadır. Bu çalışma, kentte yön bulma davranış kalıplarının; kullanıcı odaklı ve kentsel algı açısından zengin kentsel alanların geliştirilebilmesinde pekiştirmeli öğrenme yöntemi ile katkıda bulunmaktadır.

Anahtar Kelimeler: Davranışsal Kalıplar, Motivasyon Merakı, Nöro-Şehircilik, Pekiştirmeli Öğrenme, Kentsel Tasarım.

Teslim Tarihi: 08.07.2024
Kabul Tarihi: 25.08.2024

Sorumlu Yazar:
mahad.asdera@gmail.com

Imhemed, M. M. E., & Uzun, C. (2024). Pekiştirmeli öğrenme yoluyla bir etmenin kentsel çevrede yol bulma değerlendirilmesi. *JCoDe: Journal of Computational Design and Engineering,* 5(1), 259-278. https://doi.org/10.53710/jcode.1512798

1. INTRODUCTION

Neurourbanism studies the interlink between neuroscience, psychology, and urban planning to concordantly understand how a city's environment influences individuals' urban perception, cognitive function, and their navigation of it (Adli et al., 2017). As a result of escalating urban growth and the challenges that come with it, this research field came to be (Pykett et al., 2020). Adding to the cognitive perception and thus function of a city, neurourbanism looks to appropriate urban environments through considering elements like urban design and essentially how it can shape a user's perception and navigation (Salesses et al., 2013). This study subject matters because it is imperative for designing cities in the way that strengthens the link concerning a city's perception along with its navigational plans (Jeffery, 2019).

In the field of neurourbanism, the integrations of machine learning (ML) algorithms, like reinforcement learning (RL), are paving the way for meaningful interactive environments through their additions of cognitive and perceptive functions that come with developing urban spaces (Makanadar, 2024; Son et al., 2023). RL involves systems inhibited by self-referential agents that consequently learn from their actions (Sutton & Barto, 1999). With this framework, it has the potential of managing urban pathway routes as well as suggesting better navigational systems as a way of shaping efficient urban systems that assist city perception in users (Williamson, 2019; Ghazal et al., 2021). RL may assist urban planners in generating adaptive environments that respond to changing conditions and community needs by facilitating data-driven decisions and using agent-based modeling techniques (Cutitoi, 2022). This integration is vital in endorsing the improvement of cities that are both efficient in navigation as well as conducive to psychological and cognitive perceptions.

To examine the multi-layered relationship that connects RL and neurourbanism, studying different user behavioral trends in an area accentuates the prospective to design environments that value navigational urban perception (Portugali & Haken, 2018). Through learning from environmental data, RL can be used to heighten urban planning methods that come alongside bettering navigational routes in a city, allocating wayfinding solutions, and even through analyzing behavioral patterns that individuals may showcase in a space (Zhang et al., 2022). Additionally, conclusions from these methods in neurourbanism can contribute to the use of RL agents in urban environments by studying their capability to mimic certain human decision-making qualities and perceptual responses (As et al., 2022).

Neurourbanism's main idea revolves around neural processes that affect and guide a users' urban perception of a city. With this idea in mind, it relates to the understanding of the behavior of the flâneur, who is an urban explorer that curiously perceives and navigates the city in a detailed manner (La Rocca, 2017; Murail, 2017; Leomi, 2015). In this context, the flâneur then connects to the task of a RL agent in the concept of neurourbanism where just like the urban explorer, the agent curiously navigates their digital environment with the goal of perceiving it as a whole and making sense of it (Botteghi et al., 2021; Nilsson, 2011). So, through mirroring this exploratory behavior of the flâneur, agents can be deployed in mimicked environments where they can uncover behavioral patterns and trends that can inform urban planning to be more user-centric with a principal theme of perceptive wayfinding. Holding a promise of augmenting urban spaces that better align with urban perception, this unique synergy between RL and the foundations of neurourbanism supports the idea designing environments that increase perceptual and navigational quality (Heino, 2020; Phillips et al., 2015).

2. A FUSION OF NEUROURBANISM AND REINFORCEMENT LEARNING

The fusional synthesis of the field of neurourbanism and the algorithm of RL offers a conventional method to urban design in a way that uses this algorithm to enhance the cognitive perceptiveness of an urban space (Bibri et al., 2024). Considering neurourbanism's attentiveness on cognitive functional effects in urban environments, using RL gives designers the chance to dynamically correlate these concepts as its agents learn from interactions within an urban system with the intent of bettering it (Arbib, 2021). As a way of addressing differing urban implications posed by urbanization, this fusion allows urban designers to create urban spaces that advocate for proactively adding urban perception quality (Banczyk & Potts, 2018).

Neurourbanism stresses the creation of urban environments that offer cognitive functionality to residents in the way that is sets out a perceptive framework that re-imagines urban planning (Ndaguba et al., 2022). The study by Ndaguba et al. (2022) identifies central themes in neurourbanism research, including cognitive perception and urban stress, where it accents the prominence of urban spaces in reducing psychological strain, increasing cognitive clarity, as well as creating perceptually and thoughtfully designed environments. By forming a link between urban studies and neuroscience, neurourbanism can enlighten the expansion of urban layouts and systems that boost users' quality of life, thus specifying a framework for future urban planning and design initiatives (Baumann et al., 2020).

Neurourbanism also highlights the link between perceptual engagement and navigation with urban planning and design, in the way that it improves cognitive function (Xu et al., 2023; Küçük & Yüceer, 2022). Urban perception and wayfinding, that includes street perception and enclosure, impressions an individual's city perception and their navigational techniques through urban planning, correlates with neurourbanism's aim of spaces that generate functional cognitive clarity (Tolunay, 2022). Görgül and Özkan's study (2024) concluded that the outlined street silhouettes surrounded by elements affected the sense of spatial clarity of users and their perception of that specific space.

In the subject of urban design, RL algorithms are employed to analyze pedestrian pathway suggestions and controlling the flow of traffic in roads (Ye et al., 2021). These algorithms are able to make adaptive modifications that add to the perceptual quality of an urban environment, in the process that they continuously learn from the system's real-time information (Zhang et al., 2022). RL can also, in the quest to make urban environments more conductive to cognitive function, be employed in advocating for enhanced sensory stimuli in an urban layout (As et al., 2022; Tewari et al., 2023; Kee & Ho, 2024). Expending RL to develop urban navigational strategies also involves the redesign of space usage and spatial street layouts by suggesting better-suited pathways (Zheng et al., 2023; Son et al., 2023; Han et al., 2021).

RL, curiously motivated in the urban context, uses intrinsic behaviors to develop exploratory perceptions in an environment layout (Botteghi et al., 2021; Huang et al., 2021). With the foundations of urban explorations that are shaped by motivational curiosity, this approach can be applied to RL agents that actively navigate and explore environmental layouts. In the way that they learn from their actions and their consequences like humans do, these agents essentially mimic a human being's intrinsic curiosity (Deshpande et al., 2021). This method can be used in prioritizing the explorations of unfamiliar urban spaces to suggest efficient navigational map coverages (Botteghi et al., 2021).

Linking RL methods with urban design has the prospective to suggest contemporary navigational outputs that are motivated by users' curiosity-driven behavioral patterns (Bouton et al., 2019; Makanadar, 2024). Bearing in mind neurourbanism's concentration on urban perception effects in environments (Küçük & Yüceer, 2022), its intersection with curiosity-motivated RL can cultivate navigation and wayfinding in cities (Ye et al., 2021). This interaction between the two fields aims to design urban spaces that are perceptive in their cognitive functionality, reflecting neurourbanism's ideology that is advocating for a city's urban perception (Görgül & Özkan, 2024; Zheng et al., 2023).

The constant change in user preferences as well as the shifting social and environmental conditions calls for conventional design methodologies. With these concepts, simulation studies let designers mimic complex real-world scenarios using RL algorithms (Intrator & Intrator, 2001), that feature training agents to learn from their actions in an alike way to how a human being would. Simulation studies can help in providing design solutions through the investigations of an agent's curiosity-motivated behavioral patterns in an urban context. Moreover, using Unity's ML-Agents toolkit (Juliani et al., 2018) allows urban scenarios to be simulated in a digital environment where agents learn through curiosity-motivated explorations, as a contemporary approach to study multi-layered urban systems that traditional methods struggle to analyze. Featuring agents with the attitude of the flâneur and using an agent-based model (ABM) simulation (Macal & North, 2009), this study analyzes the behavioral patterns suggested by an agent's curiosity-motivated exploration. It focuses on the Sultan Ahmet Mosque neighborhood in Istanbul, examining how curiosity, an intrinsic motivation (Silvia, 2012), influences an agent's behavior in navigating and understanding their surroundings through the behavioral patterns and trends it showcases in real-time.

3. METHODOLOGY

This study employs an ABM simulation in union with RL to explore the impact of curiosity on an agent's behavioral patterns within Istanbul's Sultan Ahmet Mosque neighborhood (**Figure 1**). ABM simulates individual agent behaviors in complex systems used to theorize very complex virtual environments that are resided by independent and self-referential agents (Macal & North, 2009). For this study, this ABM simulation method is applied in use of an RL algorithm, where the agent strategizes to make decisions and learns efficient navigational patterns through interactions based on the feedback, through its model brain, it obtains from the system being either positive or negative. "Rewards" are positive reinforcements awarded to the agent and processed within their brains because of desirable behavior that motivate them to continue this behavior, whereas "Punishments" are negative reinforcements that are a result of undesirable behavior that discourage them from repeating certain behaviors (Sutton, 1992). Unity's ML-Agents toolkit facilitates this process, providing an open-source platform for the creation of simulated environments where RL teaches agents through rewards and punishments (Juliani et al., 2018). The Unity ML-Agents toolkit comprises sensors, agents, and an academy that manage simulation steps and agent interactions, where agents mimic human behaviors to enhance learning efficiency (Lanham, 2018).

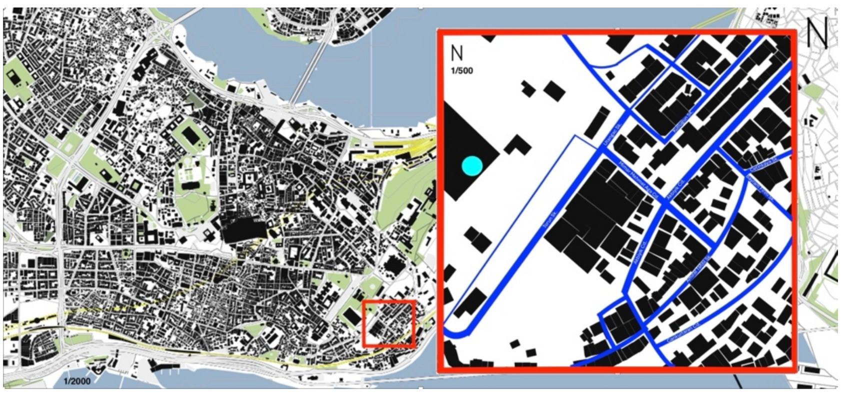


Figure 1: The Sultan Ahmet site with landmark. (map from schwarzplan.eu).

3.1 Study Area and Its Design Criteria

The reason that this neighborhood was selected is because the Sultan Ahmet Mosque is widely known by many as an iconic landmark and its reputations as a tourist attraction, built in 1916, and serving as a symbol and integral part of Istanbul's cultural, historical, and religious identity. The Sultan Ahmet Mosque neighborhood environment, modelled in 3D and scaled for performance (**Figure 2**), enables testing within a simplified urban setting. In terms of its physical features and attributes, it was modelled as simple as possible, excluding urban elements like trees, most physical features such as roads, and moving objects like people for testing purposes. In this study, the environment's building blocks, and side walls have box colliders with the "Is Trigger" option enabled to trigger punishments when the agent interacts with them, signaling undesirable actions (Engelbrecht, 2023). The agent's target, a sphere representing the Sultan Ahmet Mosque, also has a box collider to trigger rewards, guiding the agent's behavior towards the landmark.

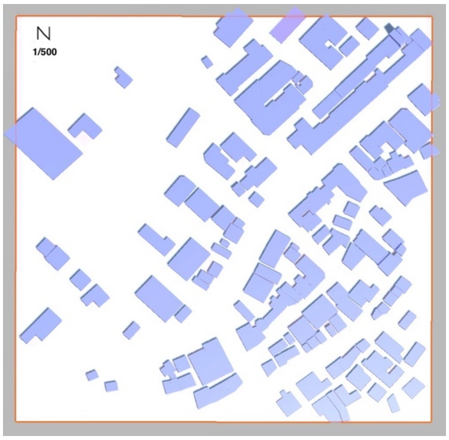
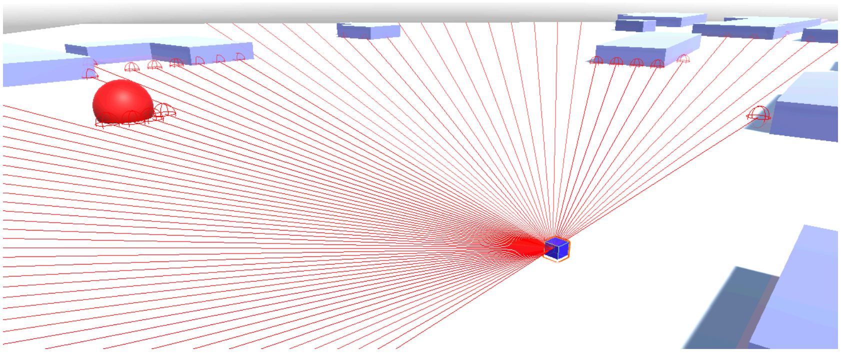


Figure 2: Sultan Ahmet neighbourhood digital environment (created by author).

The agent is designed as a minimal cube for simplicity. It represents the flâneur as an urban explorer, navigating the urban environment for the first time. The agent interacts with the environment and other objects through a box collider and a Rigidbody component, allowing it to physically navigate the space. To simulate human-like perception, a Ray Perception Sensor 3D component is attached to the agent. This sensor enables the agent to detect objects and respond accordingly by acquiring rewards and punishments, depending on the type of object detected. For example, the agent earns rewards when it detects an object tagged as "PinBall" and receives a punishment when encountering an object tagged as "Wall" (**Figure 3**). This setup is intended to mimic human peripheral visions and perception, helping the agent navigate the environment more efficiently.

Figure 3: Agent's perception sensors detecting environment (created by author).



3.2 Model Training and Evaluation

The reward design in Unity's Python C# script guides the agent's brain to make decisions and improve over time during the training process (Juliani et al., 2018). The agents' training process includes the start of their actions at the beginning of each episode, which also features indicating where the respawn locations occur, as well as their actions throughout the environment. The agents' actions are shaped by the consequences they receive, so rewards are desirable outcomes and punishments are negative ones. During training, agents' performances are monitored, and behavioral patterns are analyzed, guiding agents toward preferred outcomes and enhancing their decision-making abilities (Engelbrecht, 2023).

Training involved 6,000,000 steps conducted over a total of 300 minutes, simulating the agents' behavior as if they were on a continuous 5-hour exploration in the study area. This simulation compared two types of agents: one with a "Simple" brain model and another with a "Complex" brain model, using Unity's Inference behavior training (Juliani et al., 2018). The "Complex" agent constantly updates its decision-making processes in real-time, mimicking a more adaptive and responsive cognitive function. This model was designed to emulate a curiosity-driven approach, where the agent is motivated to explore novel stimuli and adjust its behavior based on newly acquired information. In contrast, the "Simple" brain model lacks this update feature and operates with a fixed decision-making process, which limits its ability to explore and adapt.

The study aimed to compare the effect of curiosity on behavioral patterns of both the agents in their quest to find the target (Sultan Ahmet Mosque). The curiosity component is integral to the "Complex" agent’s ability to seek out new paths and adapt to spontaneous events, thereby enhancing its navigational abilities. To ensure robustness, the simulation comparison was run a couple of times to reduce potential biases and provide a clear understanding of how curiosity affects behavioral patterns.

The training process was done across varying difficulty levels, as “Easy”, “Medium”, and “Difficult” (**Figure 4**). The different levels were opted according to the kinds of routes that were able to be taken by the agent, their perceptibility, and their distance from the target. This is where each agent’s respawn location begins during the training. For instance, the “Easy” path has a higher perceptibility and is closer to the target (approx. 500m), whereas the “Difficult” path has a lower perceptibility and is further from the target (approx. 510m). This was done to further compare their curiosity impacted behaviors in different respawn points, testing whether a further location to the target or a cluster of buildings in the agents’ way affects the behavioral trends in search of the target.

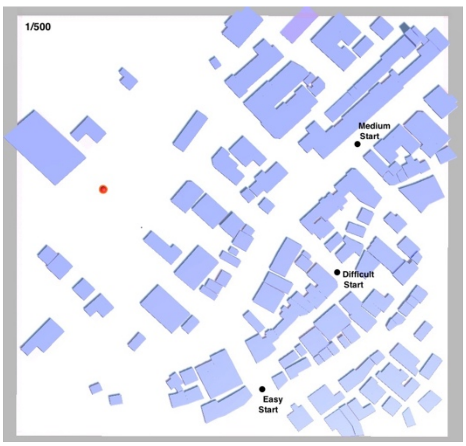


Figure 4: Agent’s difficulty level starting locations (created by author).

This study's evaluation method involved detailed observation of the agent's exploratory paths to the target. Each training session was meticulously recorded, tracking routes on a diagram of the digital environment. These routes were categorized and color-coded to reflect their frequency of use: "Primary", shown in orange, represent the most frequently taken paths: "Secondary" routes, shown in blue, indicate the second most frequently taken paths; and "Random" routes, shown in pink, correspond to infrequent and non-repetitive paths that the agent took at random intervals.

4. FINDINGS AND DISCUSSION

In the “Easy” level, both “Complex” brain and “Simple” brain agents predominantly followed the same primary path, with the “Simple” brain agent exhibiting greater random path exploration because of its lack of memory in effective routes (**Figure 5**). In the “Medium” level, the “Simple” brain agent continued exploring varied paths driven by curiosity, while the “Complex” brain agent increasingly relied on learned, shorter paths that led it to the target (**Figure 6**). In the “Difficult” level, both agents showcased very similar path preferences and trends, however the “Complex” brain agent contrastingly displayed slightly more diverse random paths (**Figure 7**).

Figure 5: Agent’s “Easy” level behavior pattern (created by author).

Figure 6: Agent’s “Medium” level behavior pattern (created by author).

Figure 7: Agent's "Difficult" level behavior pattern (created by author).

Among all three difficulty levels, the agents' behaviors displayed the influences of curiosity and the impertinence of learned experiences in the navigation process. The "Simple" brain agent's widespread exploration of random paths in the deficiency of an updated data brain underlines the intrinsic motivation of curiosity in pathfinding (**Figure 8**). Contrarywise, the "Complex" brain agent's dependence on its updated data to recall effectual routes exemplifies the guidance of experience on decreasing exploratory behaviors over time, as it earned more rewards overtime (**Figure 9**). This study's discoveries illuminate the convoluted interaction concerning curiosity, experience, and navigational performance in independent agents in an urban setting.

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Simple Brain        Step: 50000. Time Elapsed: 102.194 s. Mean Reward: -5.000. Std of Reward: 0.000.
Cyborg's Behaviour. Step: 100000. Time Elapsed: 195.741 s. Mean Reward: -5.000. Std of Reward: 0.000.
Cyborg's Behaviour. Step: 150000. Time Elapsed: 287.273 s. Mean Reward: -5.000. Std of Reward: 0.000.
Cyborg's Behaviour. Step: 200000. Time Elapsed: 375.909 s. Mean Reward: -4.901. Std of Reward: 1.472.
Cyborg's Behaviour. Step: 250000. Time Elapsed: 463.349 s. Mean Reward: -3.121. Std of Reward: 6.149.
Cyborg's Behaviour. Step: 300000. Time Elapsed: 551.553 s. Mean Reward: 2.849. Std of Reward: 10.539.
Cyborg's Behaviour. Step: 350000. Time Elapsed: 639.137 s. Mean Reward: 5.214. Std of Reward: 10.972.
Cyborg's Behaviour. Step: 400000. Time Elapsed: 726.938 s. Mean Reward: 6.284. Std of Reward: 10.996.
Cyborg's Behaviour. Step: 450000. Time Elapsed: 815.727 s. Mean Reward: 8.460. Std of Reward: 10.721.
Cyborg's Behaviour. Step: 500000. Time Elapsed: 904.585 s. Mean Reward: 10.734. Std of Reward: 9.929.
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Figure 8: Agent's "Simple" brain's learning rate (created by author).

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Complex Brain       Step: 50000. Time Elapsed: 163.877 s. Mean Reward: -5.000. Std of Reward: 0.000.
Cyborg's Behaviour. Step: 100000. Time Elapsed: 259.691 s. Mean Reward: -5.000. Std of Reward: 0.000.
Cyborg's Behaviour. Step: 150000. Time Elapsed: 349.378 s. Mean Reward: -3.952. Std of Reward: 4.685.
Cyborg's Behaviour. Step: 200000. Time Elapsed: 438.074 s. Mean Reward: 2.875. Std of Reward: 10.547.
Cyborg's Behaviour. Step: 250000. Time Elapsed: 525.771 s. Mean Reward: 5.834. Std of Reward: 10.999.
Cyborg's Behaviour. Step: 300000. Time Elapsed: 614.380 s. Mean Reward: 7.673. Std of Reward: 10.872.
Cyborg's Behaviour. Step: 350000. Time Elapsed: 703.317 s. Mean Reward: 10.661. Std of Reward: 9.964.
Cyborg's Behaviour. Step: 400000. Time Elapsed: 793.423 s. Mean Reward: 11.985. Std of Reward: 9.229.
Cyborg's Behaviour. Step: 450000. Time Elapsed: 883.724 s. Mean Reward: 12.221. Std of Reward: 9.072.
Cyborg's Behaviour. Step: 500000. Time Elapsed: 973.994 s. Mean Reward: 12.278. Std of Reward: 9.033.
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Figure 9: Agent's "Complex" brain's learning rate (created by author).

Distinctive behavioral patterns surfaced with a link to the agent and how it behaves when motivated by curiosity during the observational interpretations of the training sessions, exhibiting sufficient conceptions into their navigation movements and their pathway tendencies. Interestingly, the agents kept taking the paths they continuously recognized. In addition, with the "Simple" brain agent, it found a moderately easy or straightforward path that directed it towards the target, and it continued to take that path and overlooked perplexing routes. From the agent's curious perception of the city, it became familiar with certain routes through repetitive exposure to the environment, this familiarity developing from its repeated encounters with the environment which allowed it to cultivate a basic understanding of the layout. With a "Simple" brain model present, the agent's familiarity is not the actual result of true learning in the sense of adapting behaviors, based on rewards or feedback, and instead it unintentionally "learned" certain paths simply by repeated interaction with them.

When the results are considered in the light of neurourbanism, it is interpreted that these behavioral trends, which showcase the agent's route preferences, strengthens the idea of environmental familiarity in the way that it leads navigational behaviors. These study's comprehensions align with neurourbanism with the emphasis on cognitively perceptive urban design suggestions. Evaluating these results through the perspective of neurourbanism suggests that while environmental familiarity can adhere for navigation efficiency, true cognitive adaptation and resilience require mechanisms that enable agents, and by extension humans, to dynamically respond to changing urban context through meaningful interactions. This method therefore presents a promising avenue for exploring and bettering urban designs that promote urban cognitive perception, strengthening the link between RL and neurourbanism.

The discussion identifies several limitations of this study that impact its applicability in real-world architectural contexts, despite providing valuable insights into curiosity-influenced behavior. Firstly, the simulation used a small and simplified sample size of an Istanbul neighborhood, which may not fully capture the complexity of its urban features such as trees, monuments, and other physical features. Additionally, the study did not incorporate moving objects, such as people or vehicles, which are crucial components of real urban environments. When importing the site map into Unity, it was scaled down to simpler dimension due to the original size's complexity and computational rendering constraints. These modifications may limit the generalizability of the results. Furthermore, while the simulation provides a controlled environment for studying agent behavior, it may not entirely mimic the realness aspect and the unpredictability of urban environments, human behavior, and perception.

5. CONCLUSION

To study the influence that curiosity has on agents' behavioral trends in Istanbul's Sultan Ahmet Mosque neighborhood, this study used an RL algorithm approach in an ABM simulation. The methodology integrates ABM to simulate individual agent behaviors in complex systems, using Unity's ML-Agents plug-in, and RL algorithms to expediate decision-making and learning through consequences. This approach enabled the agents to engage in curiosity-driven navigation, which significantly influenced their exploration and movement patterns.

The findings reveal that curiosity-driven navigation led agents to exhibit distinctive behavioral patterns, particularly in their exploration of different areas within the urban environment. This behavior was evident as agents developed unique path preferences, repeatedly using the Sultan Ahmet Mosque as a reference point to construct a comprehensive mental map of the environment. The study stresses that repetitive exposure and experience, driven by curiosity, influentially shape these navigational behaviors.

Specifically, the exploration of curiosity in agents revealed distinctive differences in behavior across three types of difficulty levels associated with their respawn locations in the environment. The study found that:

a) Curiosity does certainly influence the agent as it motivated it to explore different areas of the environment, developing unique path preferences and using the Sultan Ahmet Mosque target as its point of reference to create a comprehensive mental map of the environment.

b) During the RL learning process, architects can form interactions with the agent through making modifications and controlling the C# script reward design, where they can give instructions, ultimately communicating with it.

c) From such experiences, architects, urban designers and planners can use this approach to generate adaptive design solutions by testing it in different simulated urban scenarios that imitate real-life agendas, to explore behavioral patterns and user preferences.

In conclusion, the findings offer insights to urban planners and designers, emphasizing the potential of curiosity-driven navigation in shaping behavioral patterns and cognitive responses in urban spaces. This approach can be used in elevating and generating adaptive design solutions by testing it in different simulated urban scenarios that imitate real-life settings, to explore behavioral patterns and preferences. Integrating the principles of neurourbanism, this study features the potential of incorporating neuroscientific insights and RL agents to design urban environments that are psychologically perceptive. Ultimately, by understanding how different urban forms affect human behavior and cognitive responses, urban planners and designers can adhere for urban spaces that encourage cognitive perceptiveness and function. Neurourbanism advocates for considering the human brain's response to the built environment, and so this approach allows for the simulation and refinement of urban designs based on real-world psychological and behavioral data.

Acknowledgements

This research study is based on the master's thesis titled "A Cyborg's Perception of the City" supervised by Assist. Prof. Dr. Can Uzun.

Conflict of Interest Statement

The manuscript is entitled "Assessment of an Agent's Wayfinding of the Urban Environment Through Reinforcement Learning" has not been published elsewhere and that it has not been submitted simultaneously for publication elsewhere.

Author Contribution

The authors declare that they have contributed equally to the manuscript.

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Neuroscience and Spatial Design Bibliometric Analysis in Web of Science Database

Yaren Şekerci [1]

ORCID NO: 0000-0003-4509-6299 [1]

[1] Antalya Bilim University, Faculty of Fine Arts and Architecture, Interior Architecture and Environmental Design, Antalya, Türkiye

This paper presents a comprehensive bibliometric analysis on the convergence of neuroscience and spatial design research. Using a two-step process, an initial keyword search identified 296 papers with terms like 'EEG' and 'Neuro' alongside 'Architecture,' 'Urban Design,' 'Product Design,' and 'Interior Design.' Subsequent filtering by publication date (2003-2023), language (English), document type, and categories refined this to 64 papers. Recent trends show a shift from architecture-focused studies to those emphasizing interior architecture and the use of virtual reality as a research tool. The increase in publications since 2018, peaking in 2022, indicates growing scholarly interest. This study underscores the potential of integrating neuroscience in spatial design to improve human well-being and highlighting future research directions for spatial designers. The findings reveal an evolving focus on stress reduction, biophilic design, and the enhancement of human well-being through design. This paper aims to provide a scientific foundation for user-centered and aesthetically pleasing environments.

Received: 20.07.2024
Accepted: 21.09.2024

Corresponding Author:
yaren.sekerci@antalya.edu.tr

Şekerci, Y. (2024). Neuroscience and Spatial Design Bibliometric Analysis in Web of Science Database. *JCoDe: Journal of Computational Design, 5*(2), *279-300.* https://doi.org/10.53710/jcode.1519629

Keywords: Interior Architecture, Spatial Design, Bibliometric Analysis, Neuroscience.

Web of Science Veritabanında Nörobilim ve Mekânsal Tasarım Bibliyometrik Analizi

Yaren Şekerci [1]

ORCID NO: 0000-0003-4509-6299 [1]

[1] Antalya Bilim Üniversitesi, Güzel Sanatlar ve Mimarlık Fakültesi, İç Mimarlık ve Çevre Tasarımı, Antalya, Türkiye

Bu makale, nörobilim ve mekânsal tasarım araştırmalarının kesişimi üzerine kapsamlı bir bibliyometrik analiz sunmaktadır. İki aşamalı bir süreç kullanarak, ilk anahtar kelime araması 'EEG' ve 'Neuro' gibi terimlerle birlikte 'Mimarlık,' 'Kentsel Tasarım,' 'Ürün Tasarımı' ve 'İç Mimarlık' terimlerini içeren 296 makale belirlemiştir. Yayın tarihi (2003-2023), dil (İngilizce), belge türü ve kategorilere göre yapılan sonraki filtreleme ile bu sayı 64 makaleye indirilmiştir. Son trendler, mimarlık odaklı çalışmalardan iç mimarlık ve sanal gerçekliğin bir araştırma aracı olarak kullanıldığı çalışmalara doğru bir kayma olduğunu göstermektedir. 2018'den bu yana artan yayın sayısı, 2022'de zirve yaparak, akademik ilginin arttığını göstermektedir. Bu çalışma, insan refahını artırmak için nörobilimin mekânsal tasarıma entegrasyonunun potansiyelini vurgulamakta ve mekânsal tasarımcılar için gelecekteki araştırma yönlerini öne çıkarmaktadır. Bulgular, stres azaltma, biyofilik tasarım ve insan refahının tasarım yoluyla iyileştirilmesine yönelik evrilen bir odağı ortaya koymaktadır. Bu makale, kullanıcı merkezli ve estetik açıdan hoş mekanlar için bilimsel bir temel sağlamayı amaçlamaktadır.

Anahtar Kelimeler: İç mimarlık, Mekansal Tasarım, Bibliyometrik analiz, Nörobilim.

Teslim Tarihi: 20.07.2024
Kabul Tarihi: 21.09.2024

Sorumlu Yazar:
yaren.sekerci@antalya.edu.tr

Şekerci, Y. (2024). Web of Science Veritabanında Nörobilim ve Mekânsal Tasarım Bibliyometrik Analizi. *JCoDe: Journal of Computational Design, 5*(2), *279-300*. https://doi.org/10.53710/jcode.1519629

1. INTRODUCTION

In recent years, interdisciplinary studies have grown in popularity, with neuroscience and spatial design research standing out for their effective and insightful multidisciplinary collaborations. Exploring these topics through bibliometric analysis provides a valuable chance to better understand the focus and convergence of neuroscience and spatial design, offering information on the changing environment of these collaborative initiatives. Such an analysis will not only outline the current state of research, but will also highlight emerging trends and promising areas for future investigation, making a significant contribution to the literature. This study seeks to illustrate the dynamics of multidisciplinary research by mapping the intersections and divergences within different areas, emphasizing their importance in furthering our understanding of the complex link between neural mechanisms and environmental settings.

Taşlı Pektaş (2021) conducted a bibliometric analysis to research spatial cognition in neuroscience and architecture. Our research stands out by providing a greater bibliometric scope, advanced analytical approaches, and in-depth temporal insights, thereby enriching our understanding of multidisciplinary research dynamics.

This study investigates the studies in the fields such as;

• interior architecture (Higuera-Trujillo et al., 2020; Hu et al., 2021; Yeom et al., 2021; Bacevice & Ducao, 2022; Jung et al., 2022; Kalantari, et al., 2022; Kong et al., 2022; Wang et al., 2022; Awada et al., 2023; Hu et al., 2023; Jung et al., 2023; Mostafavi et al., 2023),

• architecture (Salingaros & Masden, 2010; Nanda et al., 2013; Essawy et al., 2014; Masden & Salingaros, 2014; Gallese & Gattara, 2015; Hsu, 2015; Erkan, 2018; Ambrosini et al., 2019; Chang & Jun, 2019; Djebbara et al., 2019; Rad et al., 2019; Ahlquist, 2020; Ji et al., 2020; Cheng et al., 2021; Erkan, 2021a; Li et al., 2021; Shemesh et al., 2021; Krauze & Motak, 2022; Mostafavi, 2022; He et al., 2023; Merhav & Fisher-Gewirtzman, 2023),

• landscape architecture (Kim et al., 2019; Allahyar & Kazemi, 2021; Herman et al., 2021; Nasab et al., 2022; Wei et al., 2022; Asim et al., 2023),

• and urban design (Hollander & Foster, 2016; Mavros et al., 2016; Al-Barrak et al., 2017; Albdour et al., 2022; Aliverdilou et al., 2021; Asim et al., 2023; Baumann & Brooks-Cederqvist, 2023; Erkan, 2023),

• including furniture/product design.

• Some of the studies investigates all built environment (Kaklauskas et al., 2019; Vijayan et al., 2019; Hu & Roberts, 2020; Karakas & Yildiz, 2020; Li et al., 2020; Azzazy et al., 2021; Erkan, 2021b; Kalantari et al., 2021; Mazzone & Khosla, 2021; Djebbara et al., 2022; Gharib et al., 2022; Shemesh et al., 2022; Domjan et al., 2023; Halligan et al., 2023; Guizzo et al., 2023; Rhee et al., 2023; Yu et al., 2023; Zur et al., 2023).

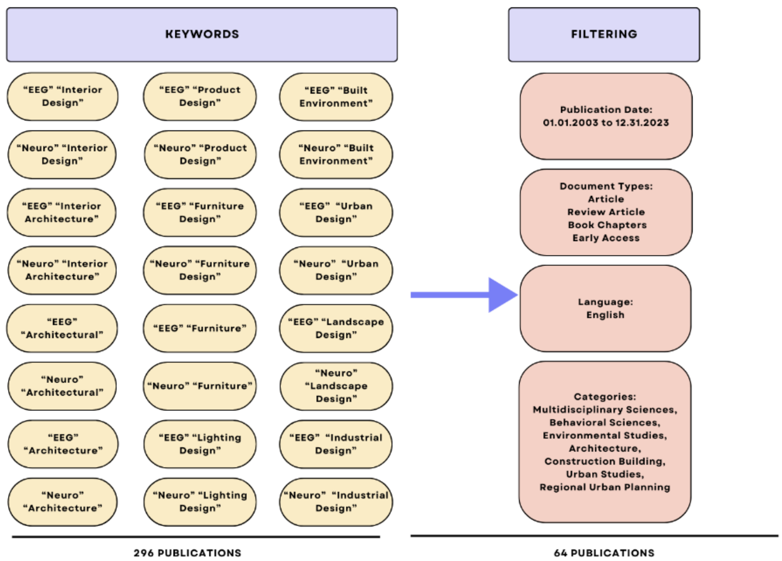
This broad inclusion provides a thorough analysis of how neuroscience overlaps with numerous design domains, aided by the purposeful use of "neuro" alongside "EEG" to catch research that employ different brain activity measurement methods such as EEG and MRI. This methodology ensures a comprehensive investigation of design and architecture.

The purpose of this project is to investigate how neuroscience and spatial design research have emerged as key topics for effective and meaningful multidisciplinary cooperation. This work uses a bibliometric analysis to find focal spots and intersections between neuroscience and spatial design, which will provide significant insights into their convergence. The study seeks to not only describe the present state of research, but also to identify new trends and prospective areas for future research, thereby significantly contributing to the literature. This work aims to map the intersections and divergences between many domains, emphasizing the necessity of comprehending the intricate relationships between neurological mechanisms and environmental circumstances, and thereby demonstrating the dynamics of multidisciplinary research.

2. METHODOLOGY

Figure 1 represents a two-stage bibliometric analysis procedure. The first stage entails a keyword search, which yields 296 papers using phrases like "EEG" and "Neuro," as well as fields like "Interior Design," "Product Design," and "Urban Design." The second stage involves filtering these publications according to several criteria, including publication date (January 1, 2003 to December 31, 2023), document type (article, review article, book chapters, early access), language (English), and category (Multidisciplinary Sciences, Behavioral Sciences, Environmental Studies, Architecture, Construction Building, Urban Studies, Regional Urban Planning). This refinement method reduces the pool to 64 papers, with the goal of narrowing the study emphasis based on certain criteria.

Figure 1: Two-Stage Bibliometric Analysis Procedure



3. FINDINGS

Figure 2 depicts the distribution of publications over time. From 2003 to 2017, the number of publications was quite low and consistent. However, there is a significant increase in frequency beginning in 2018, with a peak in 2022. This upward trend indicates an increase in academic interest in the study's themes and criteria during these years. The year 2023 also has a significant number of publications, indicating that research effort in the field has been ongoing up to that point.

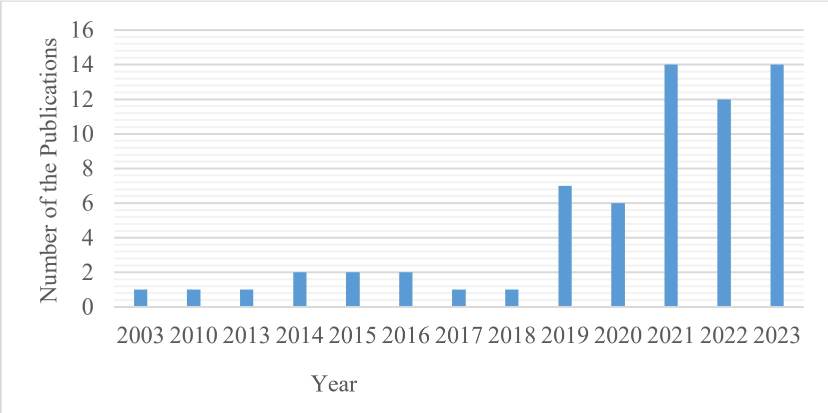


Figure 2: The Distribution of Publications Over Time

Table 1 includes the journals that have featured publications connected to the study, with a concentration on those with the most publications. Notably, 'Architectural Science Review' has the most publications, with seven, suggesting its popularity as a favored platform for communicating research in this discipline. 'Buildings' and 'Building and Environment' come close behind, with six and five articles each, indicating their importance in the academic discourse of the study's topic area. The journals 'Journal of Environmental Psychology' and 'Journal of Building Engineering' are also notable, with four and three articles, respectively, demonstrating their significance to the environmental and engineering components of the research. Lesser-cited journals, with two or one publication each, help to diversify dissemination channels, but the majority of research appears to be concentrated in the aforementioned main journals. This distribution emphasizes the study's interdisciplinary nature by incorporating architectural, environmental, psychological, and engineering elements.

Table 1: The List of the Journals Where Publications have been Featured

Journal	Number of Publications	Journal	Number of Publications
Architectural Science Review	7	Frontiers of Architectural Research	1
Buildings	6	Frontiers in Behavioral Neuroscience	1
Building and Environment	5	Heliyon	1

Journal of Environmental Psychology	4	Indoor and Built Environment	1
Journal of Building Engineering	3	International Journal of Architectural Computing	1
Sustainability	3	International Journal of Sustainable Built Environment	1
Archnet-IJAR: International Journal of Architectural Research	2	Journal of Architecture and Urbanism	1
Building Research & Information	2	Journal of Asian Architecture and Building Engineering	1
Intelligent Buildings International	2	Journal of Regional and City Planning	1
Scientific Reports	2	Landscape Architecture Frontiers	1
Urban Forestry & Urban Greening	2	MANZAR, the Scientific Journal of Landscape	1
Applied Spatial Analysis and Policy	1	Neuroscience & Biobehavioral Reviews	1
Automation in Construction	1	Open House International	1
Computer-Aided Civil and Infrastructure Engineering	1	Proceedings of the National Academy of Sciences	1
Cortex	1	PLOS ONE	1
Developments in the Built Environment	1	TEKA Commission of Architecture, Urban Planning and Landscape Studies	1
Energy and Buildings	1	Trends in Cognitive Sciences	1
Energy Research & Social Science	1	Urban Science	1

Figure 3 shows a VOSviewer network visualization displaying the co-occurrence of author keywords in a bibliometric dataset. The parameters suggest that the minimal number of occurrences for a keyword was set at one, with 256 keywords satisfying this condition and 192 of them interconnected.

The term "EEG" (electroencephalography) appears to be a central node in the network, indicating that it is a key focus within the study area. It is surrounded by clusters of related phrases that indicate the many sub-themes or fields of study related to EEG. Among these are "virtual reality," "environmental psychology," "neuro-architecture," and "biophilic design," all of which point to interdisciplinary study intersections between neuroscientific methodologies and environmental design.

The thickness of the connecting lines and the distribution of nodes indicate the strength of the links between concepts. Thicker lines indicate more frequent co-occurrences, showing stronger or more researched field linkages. Terms like "aesthetics," "built environment," and "evidence-based design" are closely related, showing that these topics are frequently discussed in the literature together.

This visualization can help academics identify critical areas of concentration, emerging trends, and potential gaps in the literature by assisting in the understanding of complicated interactions between concepts. It also demonstrates the research's multifaceted nature, embracing areas of design, psychology, technology, and environmental studies.

The keywords "greenspace" and "healing garden" are frequently used in urban planning, showing a strong preference for incorporating natural features into urban surroundings. This relationship is further emphasized in Figure 3, where the term "environmental psychology" emerges as a key focus. This finding is scarcely surprising. The interaction of spatial design and neuroscience frequently centers on the emotional and psychological states of either the designer or the user. When the emphasis is on the user's experiences within a given setting, the bulk of analyses naturally fall under the scope of "environmental psychology". This emphasizes the importance of psychological concerns in the design and evaluation of urban areas, advocating for a design approach that prioritizes human well-being by incorporating natural features and therapeutic landscapes.

Figure 3: VOSviewer Network Analysis of Author Keyword Co-Occurrence in Multidisciplinary Research (Minimum Occurrence: 1)

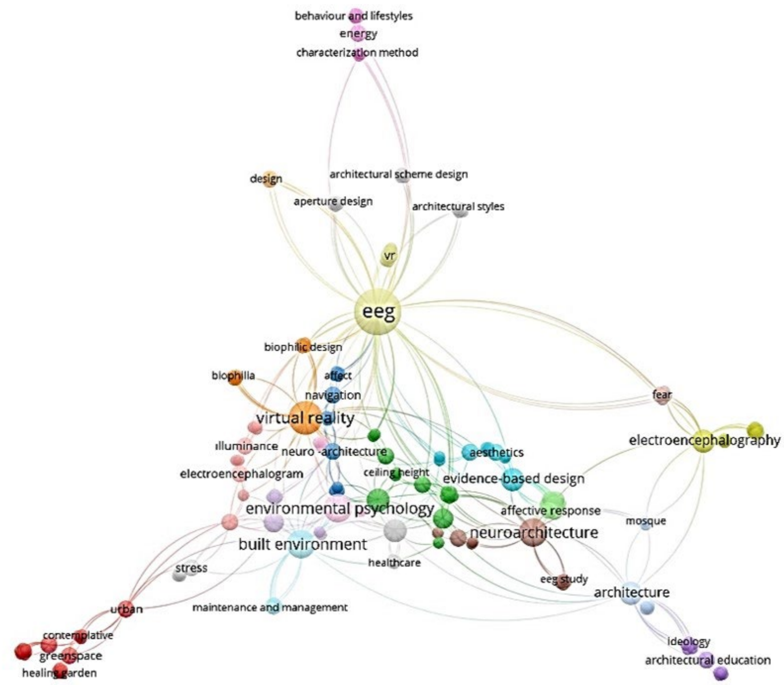


Figure 4 shows a VOSviewer network visualization map with a temporal overlay that depicts the spread of keywords over time in a set of publications. The nodes (keywords) are color-coded by year of occurrence, with the gradient spanning from 2018 to 2023. This temporal aspect helps us to see not only the links between keywords, but also how the research topic may have moved or evolved over time.

The color gradient indicates that certain themes have gained prominence in recent years. Keywords with a yellow to orange tint (for the years 2022 and 2023) may indicate emerging trends or a recent surge in interest within the research community. Keywords with a blue color (indicating earlier years) may, on the other hand, represent fundamental subjects that have maintained steady appeal over time.

The primary node, "EEG," is linked to several additional nodes, indicating its prominence in the scientific landscape throughout multiple years. The keywords associated with “EEG”, such as “virtual reality”, "environmental psychology", “built environment”, “neuro-architecture”, and “biophilic design” demonstrate an interdisciplinary study strategy that merges neuroscience with environmental design and technology. “Built environment” is associated with “stress” and “urban” keywords in the recent years works. “Urban” is also connected to “greenspace” and “healing garden” keywords. “Biophilic design” is also a trend topic in this area. It is understood that a great number of current neuroscience and spatial design related works are focusing on the green usage in the spaces. “Architectural education”, “ideology”, and “aesthetics” are relavitely old subjects in neuroscience based spatial design studies.

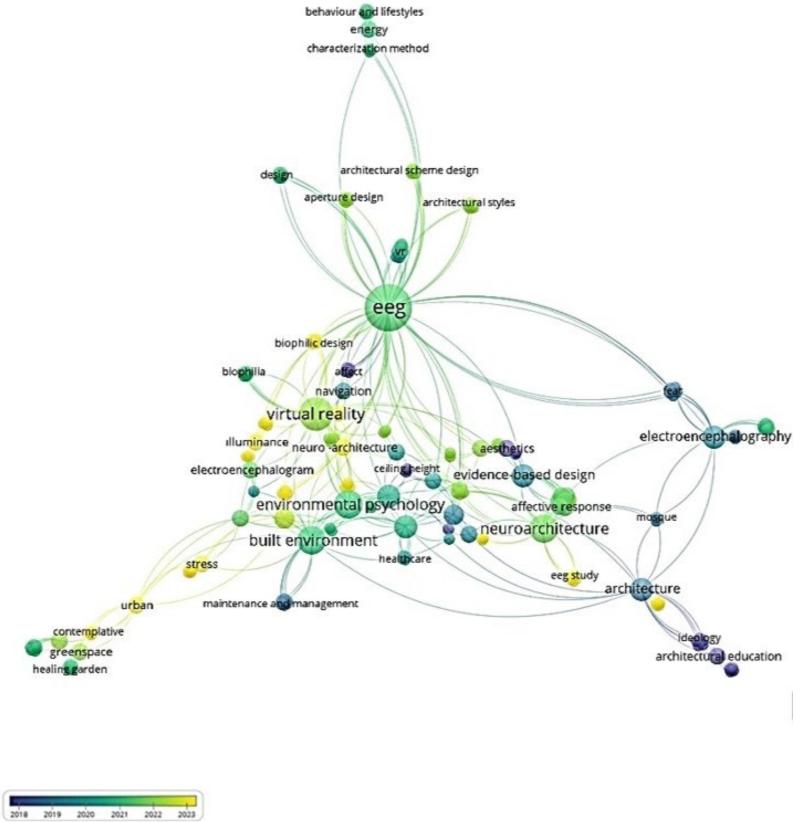


Figure 4: VOSviewer Co-occurrence Network of Author Keywords in Interdisciplinary Studies (Minimum Occurrence: 1)

Figure 5 illustrates a VOSviewer network visualization map with a set of 12 keywords, each of which appears at least three times, indicating a more focused area of study attention. All of these terms are connected, showing that they are commonly used together in the literature, implying a unified study domain.

The network's heart is "EEG," which is likely a core theme of the research and is linked to "virtual reality," indicating a convergence of neuroscientific research and immersive technology. "Neuroarchitecture" appears twice, possibly due to a difference in the dataset or as separate entries, and it forms connections with "environmental psychology" and "evidence-based design," indicating an interest in the application of neuroscience to architectural design while taking psychological effects and empirical design principles into account.

Other phrases such as "built environment" and "well-being" are related, indicating that the research is likely focused on the impact of the physical environment on human health and comfort. The phrase "electroencephalography" is linked to the term "neuroscience," indicating the methodological approach that underpins the research.
This visualization aids in identifying the fundamental concepts within the dataset and understanding how they relate to one another, providing insights into the field's interdisciplinary character, which includes neuroscience, architecture, psychology, and technology.

As stated in the "IFI Interiors Declaration" by the International Federation of Interior Architects/Designers (IFI), interior designers and architects combine human and environmental ecologies to translate science into beauty that appeals to all senses (IFI, 2011). This statement highlights the importance of the human condition and well-being in the practice of interior design and architecture. As a result, the link of the "built environment" keyword with phrases such as "well-being" and "environmental psychology" in Figure 5 gives strong evidence that study into human well-being includes both physical and mental components. The rise of transdisciplinary studies incorporating neurology and spatial design is expected to improve our understanding of the human element, which is the primary emphasis of the interior design profession. This greater understanding will, in turn, improve our ability to assess the effects of interior designs on humans, bringing design results closer to the objective of improving human well-being inside built settings. This approach emphasizes the profession's commitment to promoting human-centered design principles, ensuring that the environments we live in are not only aesthetically beautiful but also beneficial to our general health and happiness.

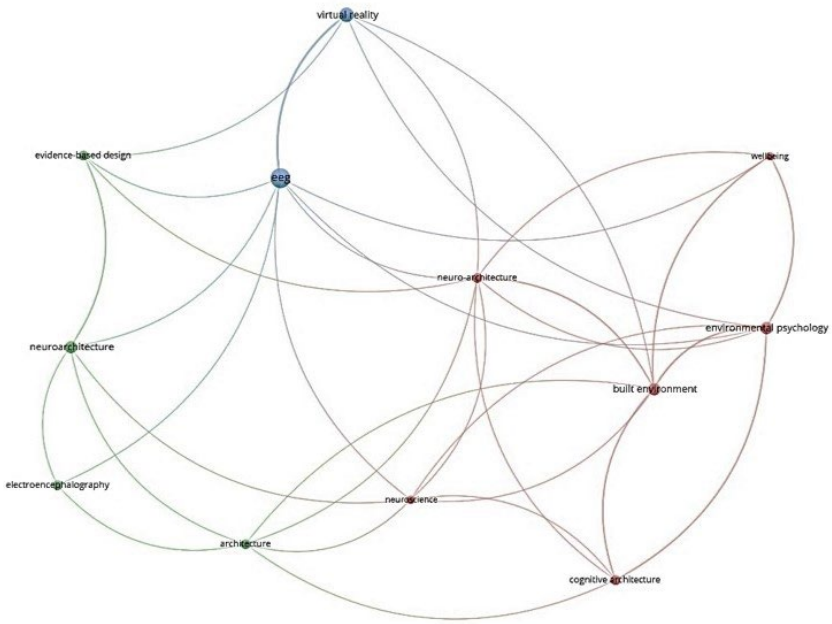


Figure 5. VOSviewer Network Analysis of Author Keyword Co-Occurrence in Multidisciplinary Research (Minimum Occurrence: 3)

Figure 6 illustrates the strong relationship between EEG and virtual reality, particularly from 2020 onward. This connection highlights the increasing interest in neuroscience-based spatial design studies where EEG is used to assess user experiences in virtual environments. The temporal dimension of the visualization further emphasizes the growing trend in this interdisciplinary field, underscoring the importance of integrating technological advancements in future spatial design research.

The main keyword "EEG" is a repeating center point, linked to a variety of research topics such as "virtual reality," "neuroarchitecture," "environmental psychology," and "wellbeing." The color coding of the lines suggests that these relationships have been active over time, with some subjects maybe gaining more attention in subsequent years, as evidenced by the shift to yellow. According to this color coding in Figure 6, "EEG-virtual reality", "EEG-well-being" connections are the most recent connections. "Neuroscience", "architecture", "cognitive architecture", and "evidence-based design" are relatively older to the other ones. Even though "neuroscience" and "architecture" keywords are losing their trend in recent years, a mix of them which is "neuro-architecture" is gaining interest in the implications of neuroarchitecture for wellness and environmental psychology. Such insights are useful for identifying patterns, understanding the current research landscape, and planning future research.

Figure 6: VOSviewer Temporal Analysis of Keyword Co-Occurrence in EEG-Related Research (2019-2022)

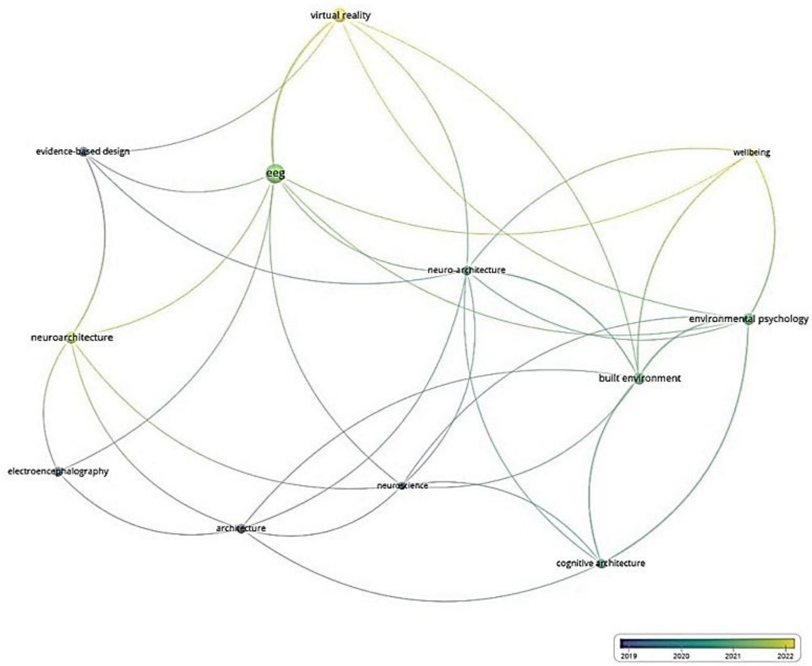


Figure 7 shows the collaborative network of researchers utilizing EEG in spatial design studies. Cornell University emerges as a significant hub, indicating its critical role in advancing research at the intersection of neuroscience and design. Such collaborations are vital for fostering interdisciplinary research and promoting innovative approaches in understanding human responses to architectural spaces.

The size of the nodes (representing individual authors) in such a network often corresponds to the number of documents published by the author, whilst the thickness of the lines between nodes frequently represents the number of co-authored articles. The visualization in this network emphasizes collaborative links rather than citation impact, with the threshold set for a minimum of two documents per author and no minimum citation count.

This type of study is useful for understanding the collaborative structure of a field, determining which scholars collaborate closely, and even estimating the importance of certain author clusters within the academic community.

According to Figure 7, the fact that just six academics worldwide have published at least two papers in the subject demonstrates the young but growing interest in the interdisciplinary topic of neuroscience and spatial design. Among these, Dr. Jesus Gabriel Cruz-Garza from the University of Houston has the most publications, as well as collaborations with all of the other well-known scholars. Notably, Cornell University appears as a major hub for this study topic, with researchers including Dr. Armin Mostafavi, Dr. James Dalton Raunds, Dr. Saleh Kalantari, Dr. Julia Kan, and Vidushi Tripathi, an undergraduate research assistant. Except for Dr. Cruz-Garza, this concentration of experts at Cornell emphasizes the university's critical role in the field's advancement.

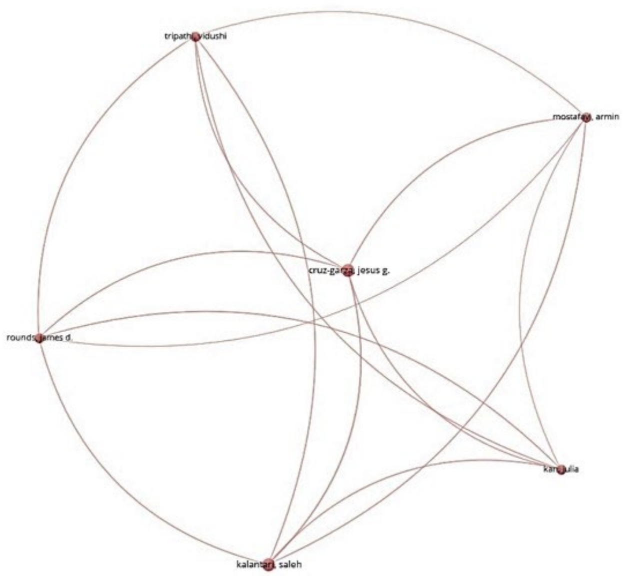


Figure 7: VOSviewer Co-Authorship Analysis of Researchers with a Minimum of Two Documents

Figure 8 appears to be a VOSviewer depiction of a co-authorship network focused on organizations that have contributed to a body of literature, with each organization publishing at least four documents. Various organizations are depicted as nodes in this network, and the links between them often signify collaborative activities between different groups in producing research output.

However, no links are displayed in the visualization, implying that the organizations named have not co-authored documents that satisfy the stated threshold or that the collaborations are outside the scope of the data obtained. It is possible that these groups are working separately in the same field or on similar themes but have not worked directly on publications that match the minimum document criteria.

Based on collaborative networks, this type of visualization can assist in identifying major institutions in a research field and their potential significance. However, the lack of connections suggests the possibility of future collaboration or an opportunity to develop collaborations between these businesses.

According to Figure 8, the universities featured in the context of interdisciplinary study at the junction of neuroscience and spatial design, such as Cornell University (USA), Qingdao University (China), Süleyman Demirel University (Turkey), and Israel Institute of Technology (Israel), play critical roles. These institutions are known for creating conditions that encourage innovative study undertaken by researchers who are committed to improving our understanding of how spatial environments influence human neurological and psychological outcomes.

Figure 8: VOSviewer Network of Organizational Co-Authorship in Scholarly Publications (Minimum Document Threshold: 4)

4. CONCLUSION

The purpose of this project is to investigate how neuroscience and spatial design research have emerged as key topics for effective and meaningful multidisciplinary cooperation. This work uses a bibliometric analysis to find focal points, connections, and intersections between neuroscience and spatial design, which will provide significant insights into their convergence. The study seeks to not only describe the present state of research, but also to identify new trends and prospective areas for future research, thereby significantly contributing to the literature, and thereby exhibiting the dynamics of multidisciplinary research.

Interdisciplinary research of neurology and spatial design, which have been accelerating since 2020, indicate that this issue is ripe for further investigation and has significant potential contributions. Early research usually focused on architecture from a neuroscience perspective, while recent trends show a shift toward interior design. With an increasing emphasis on human well-being, virtual reality has emerged as an important instrument in these investigations. Notably, research has evolved toward stress reduction and the incorporation of biophilic and urban design elements, highlighting the evolving goals of this multidisciplinary approach. This shift reflects a better understanding of how designed places can influence human psychological and physiological states, opening up new avenues for research and practical applications that prioritize health and well-being in spatial design.

Future research is likely to focus on the integration of EEG and virtual reality as robust tools for evaluating user experiences in spatial design. The findings of this study suggest that combining these methodologies will contribute to a deeper understanding of how design decisions impact psychological and physiological responses. Particularly, the use of EEG in the design of biophilic environments and stress-reducing spaces is expected to grow, offering significant potential for enhancing human well-being through design. Moreover, expanding the application of neuroscientific methods in spatial design could lead to more user-centered, emotionally responsive design solutions, thereby improving the overall quality of built environments.

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Sketching Versus Digital Design Tools in Architectural Design

Nurcan Yıldızoğlu[1]

ORCID NO: 0000-0002-4072-0366[1]

[1] Antalya Belek University, Architectural Restoration, Vocational School, Antalya, Türkiye

Sketching is a design tool that can be assumed to be ill-structured, does not offer exact solutions, is intuitive, and is open-ended in the initial stages of architectural design. Sketching creates an opportunity for architects to release their creativity and intuition, giving rise to spontaneous ideas and concepts in an organic and natural way. During the initial design phases, like in the conceptual stage of the design, designers receive aid from conventional sketching as their concepts and ideas can easily transform into tangible, real-world forms. With the development of digital design methods like CAD (computer-aided design) in pursuit of AI (artificial intelligence), it has been accepted that manual sketches are no longer the only tools used in the architectural design, and adaptation of new methods such as digital and AI-assisted tools. The diversity and evolution of tools used in architectural design, together with the integration of CAD, AI, and traditional sketching techniques, have contributed to the development of architectural design and facilitated enhanced collaboration, visualization, and efficiency across the design process. As a result, it has evolved to embrace the use of CAD, which was the first method adopted from these developments, as a basic skill in the field of architectural design education. This shift places a strong emphasis on the professional field of architectural design while also encouraging students to explore the innovative potential of CAD for design purposes. CAD presents architects with a robust platform that facilitates the creation of intricate designs and precise measurements during the initial parts of the architectural design process. Following CAD, the development of generative AI-driven tools motivates architecture students and designers to make their conceptual work more efficient and create more alternatives. Although it is known that each method mentioned has its own positive or negative aspects, it is not possible to say that any of them is used alone in architectural design processes. At this point, combining the design process with CAD and AI-supported design tools, as well as traditional manual sketching in architecture, helps develop a diverse and adaptable skill set in design. Integrating digital design tools into the architectural field emphasizes the enduring importance of traditional sketches, especially in terms of inspiration and conceptualization in architectural design, while also updating the process of design. The purpose of this paper to explore the progression of employing diverse design tools, namely manual sketching, CAD, and AI-driven design tools, throughout the architectural design process. This paper aims to understand why designers continue to use traditional sketching methods by comparing digital design tools and traditional sketching. This paper undertakes a comparative analysis of using computational design tools instead of traditional sketching with pen and pencil, aiming to juxtapose their respective benefits and drawbacks. In conclusion, although it is not yet possible to assert the superiority of one method over the other, it is evident that traditional sketching continues to hold significant relevance and effectiveness in the design process despite its long-term use.

Keywords: Design Process, Manual Sketching, CAD, Sketch-Based AI.

Received: 25.06.2024
Accepted: 27.08.2024

Corresponding Author:
nurcanyildizoglu@belek.edu.tr

Author, A. & Author, A. (2024). Sketching Versus Digital Design Tools in Architectural Design. *JCoDe: Journal of Computational Design, 5*(2), 301-316. https://doi.org/10.53710/jcode.1504947

Mimari Tasarımda Eskiz ve Dijital Tasarım Araçları

Nurcan Yıldızoğlu[1]

ORCID NO: 0000-0002-4072-0366[1]

[1] Antalya Belek Universitesi, Mimari Restorasyon, MYO, Antalya, Türkiye

Eskiz, mimari tasarımın ilk örneklerinden beri kullanılan, sezgisel ve açık uçlu olduğu düşünülen bir tasarım aracıdır. Eskiz, mimarların yaratıcılıklarını ve sezgilerini serbest bırakmaları için bir fırsat yaratır, kendiliğinden fikir ve kavramların organik ve doğal bir şekilde ortaya çıkmasına neden olur. Dijital tasarım yöntemlerinin gelişmesiyle birlikte, manuel eskizlerin artık tasarım sürecinde kullanılan tek yöntem olmadığı kabul edilmiş ve yeni yöntemlerin kullanılmasına yönelik eğilim ortaya çıkmıştır. Mimari tasarımda kullanılan araçların çeşitliliği ve gelişimi, bilgisayar destekli tasarım (CAD), yapay zeka (AI) kullanımının tasarım süreçlerine entegrasyonuyla birlikte, mimari tasarımın gelişimine katkıda bulunmuştur. Bahsedilen her yöntemin kendine has olumlu ya da olumsuz yönlerinin olduğu bilinse de mimari tasarım süreçlerinde hiçbirinin tek başına kullanıldığını söylemek mümkün değildir. Bu noktada tasarım sürecini CAD ve yapay zeka destekli tasarım araçlarının yanı sıra mimarideki geleneksel manuel eskizlerle birleştirmek, tasarımda çeşitli ve uyarlanabilir bir beceri seti geliştirmeye yardımcı olur. Dijital tasarım araçlarının mimari alana entegre edilmesi, geleneksel eskizlerin özellikle mimari tasarımda ilham ve kavramsallaştırma açısından kalıcı önemini vurgularken aynı zamanda tasarım sürecini de güncelliyor. Bu makale, mimari tasarım süreci boyunca geleneksel eskiz, CAD ve yapay zeka odaklı tasarım araçları gibi çeşitli tasarım araçlarının kullanılmasındaki ilerlemeyi keşfetmeyi amaçlamaktadır. Bu makale, günümüz tasarım süreçlerinde hala güncelliğini koruyan geleneksel eskiz yerine hesaplamalı tasarım araçlarının kullanılmasının karşılaştırmalı bir analizini üstlenmekte ve bunların faydalarını ve dezavantajlarını yan yana getirmeyi amaçlamaktadır. Sonuç olarak, her ne kadar bir yöntemin diğerine üstünlüğünü ileri sürmek henüz mümkün olmasa da, geleneksel eskizin uzun süreli kullanımına rağmen tasarım sürecinde önemli bir yer tutmaya ve etkili olmaya devam ettiği açıktır.

Teslim Tarihi: 25.06.2024
Kabul Tarihi: 27.08.2024

Sorumlu Yazar:
nurcanyildizoglu@belek.edu.tr

Yıldızoğlu, N. (2024). Mimari Tasarımda Eskiz ve Dijital Tasarım Araçları. *JCoDe: Journal of Computational Design, 5*(2), 301-316. https://doi.org/10.53710/jcode.1504947

Anahtar Kelimeler: Tasarım Süreçleri, Geleneksel Eskiz, CAD, Eskiz Tabanlı Yapay Zeka.

1. INTRODUCTION

Sketching is a powerful and oftused design tool that gives a feeling of freedom with its subjective interpretation capacity. It is rough and lacking in detail in nature, and designers use it to express and develop their concepts in the design process. Due to the opportunities it provides to designers, traditional sketching has been used since the first designers as a design tool that enables the abstract ideas of designs to become a reality by drawing ideas on paper with the help of a pencil. In addition, while drawing techniques may differ, numerous designers recognize the utilization of sketches as a crucial component within their design process (Do, 2002). With the increasing prevalence of digital design tools like Computer-Aided Design (CAD) and Artificial Intelligence (AI) in architectural design process, traditional sketching is no longer a standalone design tool. So, the architectural design processes are undergoing a transformation, shifting from conventional paper-and-pencil approaches to utilizing digital design techniques. In light of these developments, the emergence of digital design tools and their acceptance and widespread use in architectural design processes have enabled significant revolutionary improvements and advances in architectural design processes. The evolution and transformation in architectural design processes have reshaped the way architectural design is approached and practiced, paving the way for the ongoing evolution and development of these tools.

The design process is a subject that designers have been busy with for a long time. Nowadays, when the design process changes with the development of digital design tools, it is expected to accept that the design process exists based on traditional principles (Svetel et al., 2018). Digital design tools such as CAD and sketch-based AI tools are now widely used by designers in the architecture industry as accessibility has increased. Despite the evolution of these tools, their acceptance in the architectural industry, and their rapid integration into the design process, manual sketching remains an inseparable tool of the architectural design process. In the context of architectural design, although CAD and AI tools can fall under digital design tools, it is essential to distinguish between the roles of CAD and AI tools as independent techniques versus their integration into design processes. This study acknowledges the distinct characteristics of CAD and AI tools, which can vary significantly across different stages of the architectural design process. To clarify the scope of this research, the focus is narrowed to the comparison and integration of traditional sketching, CAD environments, and sketching with AI tools. This refined focus aims to provide a clearer understanding of how these specific tools interact and influence the design process, and serves to enhance the coherence of the research findings within the context of the existing literature. In line with this information, the main focus of the research is on digital design methods such as CAD and AI and the impact of these digital design tools on factors that affect the design process, such as designers' creativity compared to traditional manual sketching. It is important to comprehend how digital design tools affect creativity in the design process and to have a deep understanding of how these tools are used in architectural practices. This understanding is crucial to ensure these technologies support and enhance designers' capacity to generate ideas and innovate rather than restrict them. The primary research question examines why designers continue to use traditional sketching methods by comparing digital design tools with traditional sketching methods. Additionally, the problem statement explores why the traditional sketching method remains popular among designers despite the increasing prevalence and accessibility of digital design tools.

2. LITERATURE REVIEW

2.1 Sketching Environment in the Design Process

Sketching is a fundamental human activity widely utilized to generate conceptual and creative ideas and overcome intricate design obstacles (Akin, 1978; Goldschmidt, 1991, 2017). Although drawing styles vary in architecture to help designers explore and embody their ideas, many designers consider traditional sketching an inherent part of the architectural design (Do, 2002). The process of sketching is often commonly considered an ill-defined design tool due to its open-ended nature, which inherently requires a definitive solution to the design problem (Goel, 1995). As a part of the creative process, sketching is a brainstorming tool, avoiding details and embodying roughness (Putra et al., 2022). It facilitates the translation of abstract ideas into concrete forms that effectively communicate design concepts. In other words, sketching has been a significant communication tool for creators, enabling them to articulate their ideas during the design process (Lawson, 2002; Lee, 2017). Sketching is one of the most well-known methods in the architectural design process for abstract representation, which is traditional manual sketching via pen and pencil (Bryan, 2005; Goldschmidt, 1994).

Manual sketch acts make an essential contribution to architectural design stages because they have a crucial effect on sparking and evolving creative concepts in the initial design stage (Shih et al., 2015). They aid designers in visual reasoning and exploring spatial relationships between diagrams. Most architectural education includes utilizing traditional tools like pen and paper for crafting design and expressing designers ideas through drawing, with design thinking encompassing considerations of form and function, representing a mode of visual and spatial cognition (Do, 2002). Designers in architectural design still use manual sketching to generate new ideas, solve design problems, and express their concepts. Upon visiting previous sketches, including one's own and those of others, it is possible for new and unexpected ideas to emerge. Although designers mostly use manual sketching, especially during the initial design process in architecture, pen, and pencil are not the only tools for expressing ideas in designers' minds in tangible forms. With the evolution of computational design, different digital design tools, such as CAD and AI tools, have come to the forefront of the architectural profession and have become popular among designers.

2.2 Digital Design Tools Environment in the Design Process

The globalization of construction projects has compelled existing design tools to transition from individual design to the implosion of different design fields in order to enhance final products. Consequently, novel computational-aided design tools have emerged as a result of this shift (Goulding et al., 2014). In other words, there have been shifts in traditional sketching after the digital design era. These changes may affect the design process (Error! Reference source not found.). For example, some literature suggests that computer-aided design may negatively affect the creativity of designers (Robertson et al., 2007; Van Elsas & Vergeest, 1998; Verstijnen et al., 1998).

In contrast, Madrazo (1999) argued that digital design tools enhance comprehension of form, aiding visual cognition. Marx (2000) corroborated this notion, suggesting that immersive visualization and feedback in computer-based tools prompt designers to engage in mental imaging more frequently than traditional sketching tools. In addition, Won (2001) found that the cognitive behaviors of designers while using traditional sketching methods mirror those when using digital design tools. In addition, Bilda and Demirkan (2003), in their study on understanding the perceptual frequency of actions shown during the architectural design process, concluded that the actions shown during traditional sketching require more frequent attention changes with increasing actions compared to digital design tools and create more exploration opportunities. Likewise, Tang et al. (2011) found that digital design tools commonly used in drafting processes are very similar to the key features of traditional sketching tools in the architectural design. In addition, the mentioned study suggested that digital design did not affect the duration of explorative ideation relative to problem definition. In this regard, the use of digital design tools instead of manual sketching in architectural design has led to extensive discussions in the professional field. The utilization of traditional manual sketching methods entails inherent advantages; however, incorporating diverse digital design tools into the field of architecture has emerged as a pivotal and contemporary concern.

Table 1: Differences and similarities of the traditional sketching and digital design tools.

	Differences	Similarities
Traditional Sketching	*Creating more exploration opportunities (Bilda and Demirkan 2003) *Requiring more frequent attention changes (Bilda and Demirkan 2003)	*Cognitive behaviors of designers during use of them (Won 2001) *Commonly used in drafting processes (Tang et al. 2011) *Did not affect the duration of explorative ideation relative to problem definition (Tang et al. 2011)
Digital Design Tools	*May negatively affect the creativity of designers (Robertson et al., 2007; Van Elsas & Vergeest, 1998) *Enhancing comprehension of form, aiding visual cognition (Madrazo 1999)	

2.2.1 CAD Environment in Design Process

Using geometry and expression capabilities, CAD helps designers immerse themselves in the design process and achieve final results practically from start to finish. In this respect, it attempts to substitute traditional techniques such as sketching, which can be called a digital design methodology (Shih et al., 2015). When attempting to depict complex 3D objects, it is often challenging for 2D representations to accurately convey their intricacies. In a CAD modeling design environment, 3D objects can also be used to create 3D geometry or make changes to the model. Moreover, CAD modeling can significantly assist in design problem-solving (Shih et al., 2015). While traditional methods rely on sketching to convey essential concepts, they often fall short when dealing with complex issues, as noted by Lin (2003). Moreover, with the increasing efficiency and user-friendliness of CAD modeling programs, they are supplanting conventional paper and pencil methods, particularly within the realm of architectural conceptual design (Veisz et al., 2012). In the initial phases of the architectural design process, numerous designers, engineers, and educators use CAD tools.

On the one hand, several empirical studies show that current CAD tools can be as influential as sketching (Buchal, 2002; Hanna & Barber, 2001). Eggli et al. (1997) invented the pen-based "Quick Sketch," with a 3D modeling system now available in CAD systems, and claimed that modeling the design interactively with this system at a concept stage was slightly faster than traditional sketching. Hanna and Barber (2001), in their study of architecture students who exclusively used CAD as a design tool, concluded that the students preferred using CAD over the traditional sketching method alone.

On the other hand, some studies suggest that CAD tools negatively affect the stages of the design process (Robertson et al., 2007). The main effects are restricting the designer's thinking and fixing the designer in the design phase as the design gains detail. Continuous and excessive use of CAD can dull the designer's creative abilities. CAD often draws criticism for shifting the designer's focus toward details instead of fundamental principles during the design phase (Utterback et al., 2006). During traditional sketching, designers can quickly capture ideas and focus on the essentials. On the other hand, a CAD system needs to examine some information to create a representation of an object, and by supporting this information, the final result can be produced, which can change the focus of the designer.

CAD can replace conventional sketching tools in architectural design stages, especially in the initial conceptual design process. However, computational design methods are still in the transition and development phase (Buchal, 2002); this process is akin to the transition from handwritten documents to ubiquitous word processing. In light of the literature, it is evident that the traditional sketching and CAD method has various opportunities and challenges for designers (Error! Reference source not found.). In particular, the literature argues that the opportunities offered by the traditional sketching method for creativity are at the forefront. In contrast, CAD methods are more prominent in terms of details and complex issues in design. Considering these points, arriving at a definitive conclusion regarding the comparative value of traditional sketches versus CAD representations within the architectural design process is challenging.

2.2.2 AI-driven Environment in the Design Process

Utilizing architectural design principles and processes in the context of artificial intelligence, particularly in sketching, is of great significance. AI tools exhibit promise in enhancing architectural sketches and concepts through various means. In recent years, the utilization of generative AI has gained significant traction for cultivating creativity within various domains (Zhang et al., 2023). Such capabilities could expedite the creation of diverse design options for architects to consider or facilitate the exploration of different design concepts without requiring additional visualization methods like 3D modeling and rendering tools (Hegazy & Saleh, 2023). In other words, AI tools provide users with a wide range of design ideas and help designers recognize potential strategies and approaches to overcome design challenges (Zhou, 2021). In this direction, many AI tools can provide a basis for designers' concept ideas. Different types of generative AI tools exist, such as text-based, image-based, and sketch-based. Generative AI tools that can be trained to complete incomplete sketches or create alternative designs based on existing sketches are called sketch-based AI.

In the conceptual design phase of architecture, sketch-based AI visual prompts can inspire architects to develop multiple design options. AI can provide conceptual sketches during the early design stage, serving as examples for design discussions (Zhou, 2021). In addition, it is very advantageous for designers that AI can introduce line changes in sketches and even better understand architects' sketches and complete unfinished sketch drawings. According to Zhang's (2023) findings, designers find great value in leveraging AI-generative image design tools as they aid in generating alternative design options, sparking new creative directions, and refining existing sketches.

However, although AI-based design has positive aspects, such as producing inspiring results, studies also emphasize its negative aspects. In particular, Zhang's (2023) results showed that AI may not understand terms specific to the architectural field and can sometimes produce surreal images unsuitable for construction purposes. Sketch-based AI tools have been extensively researched in design and are increasingly advancing in interpreting hand drawings for various applications, a crucial development for designers. Baudoux et al. (2024) propose three critical features for upcoming and current sketch-based AI design tools. Integration is essential in both creating the sketch and storing features in memory. Symbolic and logical processes need to be integrated to manipulate various sources of recognition. Finally, the tools should be engaging, precise, and inspiring. To generate images, they must surpass simple geometric models.

2.3 Mixed Media Design Environment in the Design Process

Developments and studies in digital design tools have focused on integrating different design tools into various design processes to achieve final results, thereby enabling the increasing globalization of professional groups associated with construction projects, such as architecture and engineering (Shih et al., 2015). Römer et al. (2001) supported the idea that traditional sketching and CAD modeling are widely recognized and supported as the primary and most commonly utilized design tools by architects and educators in architecture. In addition, Shih et al. (2015) noted that the combination of manual sketching and CAD can be referred to as a mixed-media design environment. In addition, this article supports that the interplay between sketching and CAD modeling fosters a switching behavior that could potentially influence design processes.

Considering the challenges and opportunities of mixed media design, there is ongoing debate about applying the two methods combined in the process of design. On the one hand, during the design stages, designers are confronted with the additional responsibility of transitioning traditional sketches to CAD systems (Alvarado et al., 2002). This means that although sketching offers designers flexibility and practicality and is popular for designers to use in their early stages, it can cut into the process of design fluently, especially when designs need to be transferred from sketch to CAD (Shih et al., 2015). This process is notably time-consuming and necessitates careful attention. Likewise, using both sketches and CAD tools underlines the importance of exploring the integration between mentioned tools to avoid wasting time and losing information during the transition from manual sketching to CAD tools (Römer et al., 2001). In light of this research, another research supports that streamlining the conversion of traditional sketches into CAD tools would offer designers several advantages (Lim et al., 2001). On the other hand, some researchers support the freedom of designers to switch between sketching and CAD modeling, ignoring the time loss when switching between tools (Do, 2005; Sachse et al., 2001). In addition, Evans (1997) provides a valuable perspective on the architectural design process with his concept of "translation," suggesting that architectural drawings act as translations of ideas and contexts into physical forms. In this context, it sheds light on the naturally switching behaviors observed during the design process because these translations are not merely technical practices but are deeply intertwined with interpretive and contextual dimensions. Thus, the switching behavior is intrinsically linked to the dynamics of transforming conceptual intentions through various modes of representation, enriching the understanding of how digital design tools and traditional sketching differ in their cognitive and representational approaches. As a result, when the sketching methods in architecture are examined, although each method has its advantages and disadvantages, their advantages and disadvantages also emerge when used together (Error! Reference source not found.).

Table 2: Opportunities and challenges of the design tools.

Design Tools	Opportunities	Challenges
Traditional Sketching	*Aiding creativity and intuition (Robertson et al., 2007; Van Elsas & Vergeest, 1998; Verstijnen et al., 1998) *Ease of quickly capturing ideas and focusing on the essentials (Utterback et al., 2006)	*Falling short when dealing with complex issues (Lin, 2003).
CAD	*Assisting in design problem-solving (Shih et al., 2015) *Increasing efficiency and user-friendliness (Veisz et al., 2012)	*Restricting the designer's thinking and fixing the designer (Robertson et al., 2007) * Dulling the designer's creative abilities when excessive use (Robertson et al., 2007)
AI-driven tools	*Providing users with a wide range of design ideas (Zhou, 2021) *Helping designers recognize potential strategies (Zhang, 2023) *Providing conceptual sketches during the early design stage (Zhou, 2021)	*May not understand specific terms (Zhang's 2023) *Can sometimes produce surreal images (Zhang, 2023)
Mixed-Media Design Environment	*Switching behavior could potentially influence design processes (Shih et al. 2015). *Flexibility and practicality (Shih et al., 2015) *Supporting the freedom of designers to switch (Do, 2005; Sachse et al., 2001).	*Confronting additional responsibility of transitioning (Alvarado et al., 2002) *Can cause losing amount of time and information during transition (Römer et al., 2001)

3. CONCLUSION

Traditional sketching is a fundamental and vital tool in architectural design, especially in the initial conceptual phases. It allows architects to reflect intensely on and interpret their design intentions, paving the way for a more expansive exploration of potential solution ideas. In architectural design, conceptual design methods need a predominantly human-centered approach, emphasizing the power of creativity and human ingenuity. Design development predominantly relies on computer-aided methods, enabling precision and efficiency in executing intricate designs. Consequently, traditional sketching techniques continue to be prevalent in the field of architecture.

Stones and Cassidy's (2010) found compelling results when they compared students' sketching work using traditional and computational media for reinterpreting design ideas during conceptual thinking. They discovered that traditional sketches were significantly more effective in facilitating reinterpretation and the generation of design ideas. These results underscore the importance of traditional sketching methods in the design process. In the context of ongoing discussions, a group of researchers argues that traditional sketching should remain unchanged and that it is a design tool that can be used in the conceptual design stages. Another group of researchers argues that using CAD tools developed to support, extend, or change sketches can contribute to obtaining more effective results in the design stages. On the other hand, researchers looking at newer developments argue that sketch-based artificial intelligence can contribute to achieving inspiring design results. In this context, sketch-based AI design produces content through hand-drawn sketches, a combination of two tools. In addition, some advocate the mixed-media method, where traditional sketching methods are used together with computational design methods. In conclusion, it is evident that with the development of digital design tools such as CAD, in pursuit of AI, the tools used in architecture also develop and change. Although it is not yet possible to assert the superiority of one method over the other, it is evident that traditional sketching with paper and pencil continues to hold significant relevance and effectiveness in the design process despite its long-standing use.

The findings of this study, it is clear that the interaction between digital design tools and traditional sketching has significant potential in the design process. While much of the analysis has focused on pairwise comparisons between these methods, the value of using them in tandem should not be overlooked. This study focuses on a third scenario, where integrating digital design tools and traditional sketching facilitates a fluid "switching behavior" that enhances creative exploration and problem-solving. The mixed-media approach enables designers to utilize the strengths of both mediums, resulting in a more dynamic and adaptable design process. Furthermore, this research introduces a novel perspective to the existing body of literature by providing a comprehensive and intricate evaluation of how the integration of hybrid practices can elevate and enrich the design environment. This nuanced analysis offers an in-depth framework for comprehending the dynamic and evolving role of mixed media in contemporary design practice.

Acknowledgements

I would like to thank Prof. Dr. Fehmi Dogan encouraged me to work in this paper.

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Integrating Gamification with BIM for Enhancing Participatory Design

Zeynep Özge Yalçın[1]

ORCID NO: 0000-0001-9165-8999[1]

[1] Izmir Institute of Technology, Faculty of Architecture, Department of Architecture, İzmir, Türkiye

The combination of gamification and Building Information Modeling (BIM) can be described to support user participation, decision-making, and collaboration in design contexts. Within this aim, this paper presents a literature review on the potential of using gamification in the BIM framework to create immersive participatory design environments. Active involvement of stakeholders by the corporation of gamified components such as challenges and interactive simulations into the design process enables better decisions and enhances user experience. Further, gamification integrated into BIM brings the potential to improve user behavior and decision-making at all stages of the design lifecycle but also the limitations and challenges. It can encourage stakeholder interaction and provide real-time input allowing various stakeholders to make meaningful contributions towards sustainability goals. This study examines recent developments and trends in extended reality (XR), augmented reality (AR), and virtual reality (VR). These advances significantly enhance gamified Building Information Modeling (BIM) environments as being immersive. In addition, it points out some challenges, and ethical concerns encountered with these technologies. Furthermore, this paper highlights some tools and their advantages, disadvantages, pricing, and key elements. Designers can create interactive experiences by combining these technologies with virtual and physical environments. BIM environments powered by gamification can be used in BIM workflows to reach their full potential in shaping future design practices. These include ways to advance cooperative design processes by creating immersive spaces for different stakeholders' interests and keeping up with emergent technology.

Received: 27.06.2024
Accepted: 25.08.2024

Corresponding Author:
zeynepozge.yalcin@gmail.com

Yalçın, Z. Ö. (2024). Integrating Gamification with BIM for Enhancing Participatory Design. *JCoDe: Journal of Computational Design, 5*(2), 317-344. https://doi.org/10.53710/jcode.1505309

Keywords: BIM, Gamification, Immersive Places, Physical, Virtual.

Katılımcı Tasarımı Geliştirmek için Oyunlaştırmanın BIM ile Bütünleştirilmesi

Zeynep Özge Yalçın [1]

ORCID NO: 0000-0001-9165-8999 [1]

[1] İzmir Yüksek Teknoloji Enstitüsü, Mimarlık Fakültesi, Mimarlık Bölümü, İzmir, Türkiye

Oyunlaştırma ve Yapı Bilgi Modellemesi (BIM) kombinasyonu, tasarım bağlamlarında kullanıcı katılımını, karar vermeyi ve işbirliğini desteklemek için tanımlanabilir. Bu amaç doğrultusunda, bu makale, sürükleyici katılımcı tasarım ortamları oluşturmak için BIM çerçevesinde oyunlaştırma kullanımının potansiyeli üzerine bir literatür taraması sunmaktadır. Zorluklar ve etkileşimli simülasyonlar gibi oyunlaştırılmış bileşenlerin tasarım sürecine dahil edilmesiyle paydaşların aktif katılımı daha iyi kararlar alınmasını sağlar ve kullanıcı deneyimini geliştirir. Ayrıca, BIM'e entegre edilen oyunlaştırma, tasarım yaşam döngüsünün tüm aşamalarında kullanıcı davranışını ve karar verme sürecini iyileştirme potansiyelinin yanı sıra sınırlamalar ve zorluklar da getirmektedir. Paydaş etkileşimini teşvik edebilir ve çeşitli paydaşların sürdürülebilirlik hedeflerine anlamlı katkılarda bulunmasına olanak tanıyan gerçek zamanlı girdi sağlayabilir. Bu çalışma, genişletilmiş gerçeklik (XR), artırılmış gerçeklik (AR) ve sanal gerçeklik (VR) alanlarındaki son gelişmeleri ve eğilimleri incelemektedir. Bu gelişmeler, oyunlaştırılmış Yapı Bilgi Modellemesi (BIM) ortamlarını sürükleyici olarak önemli ölçüde geliştirmektedir. Ayrıca, bu teknolojilerle karşılaşılan bazı zorluklara ve etik kaygılara da işaret etmektedir. Ayrıca, bu makale bazı araçları ve bunların avantajlarını, dezavantajlarını, fiyatlarını ve temel unsurlarını vurgulamaktadır. Tasarımcılar bu teknolojileri sanal ve fiziksel ortamlarla birleştirerek etkileşimli deneyimler yaratabilirler. Oyunlaştırma ile desteklenen BIM ortamları, gelecekteki tasarım uygulamalarını şekillendirmede tam potansiyellerine ulaşmak için BIM iş akışlarında kullanılabilir. Bunlar arasında, farklı paydaşların ilgi alanlarına yönelik sürükleyici alanlar yaratarak ve gelişen teknolojiye ayak uydurarak işbirliğine dayalı tasarım süreçlerini ilerletmenin yolları yer almaktadır.

Anahtar Kelimeler: Oyunlaştırma, Mimari, Mimari Tasarım, Tasarım Stüdyosu.

Teslim Tarihi: 27.06.2024
Kabul Tarihi: 25.08.2024

Sorumlu Yazar:
zeynepozge.yalcin@gmail.com

Yalçın, Z. Ö. (2024). Katılımcı Tasarımı Geliştirmek için Oyunlaştırmanın BIM ile Bütünleştirilmesi. *JCoDe: Journal of Computational Design, 5*(2), 317-344. https://doi.org/10.53710/jcode.1505309

1. INTRODUCTION

This modern architectural technique for incorporating gamification techniques into Building Information Modeling (BIM) is still in its infancy. The new approach involves game design features such as obstacles, incentives, and interactive experiences in customary design workflows to achieve greater user motivation, decision-making, and collaboration (Selin et al., 2019; Zichermann & Cunningham, 2011). The main research method used in this study is an extensive review of the literature. With a special emphasis on participatory design and extended reality technologies, the review attempts to synthesize the body of research that has already been done about gamification and BIM integration. The way gamification has been included in BIM and participatory design processes, as well as the possible advantages and difficulties of doing so, have all been critically examined thanks to this methodology. There are two major research questions for this study: Initially, what could be the future directions and ethical challenges that can address the participatory design, cooperation, decision-making processes, and user engagement while integrating gamification approaches into BIM? This question highlights the complexity and attendant hurdles in considering the benefits and ethical issues derived from such integration. Secondly, how does participation in design throughout the lifecycle of a project change due to the adoption of gamified BIM environments? How can these be customized for different stakeholders' needs? Design projects benefit greatly from collective intelligence including these perspectives seeing that different stakeholders contribute their knowledge towards common goals. These have attractive implications for stakeholders and end users (Luck, 2003, 2007; Hou and Rios, 2003). Gamification combined with BIM offers an advanced possibility for improving collaboration, decision-making, and user involvement through the design process. This can be achieved through the gamified components that promote active participation of actors leading to improved user experiences and making informed decisions (Hanus & Fox, 2015; Hassan & Hamari, 2020; Hofacker et al., 2016). However, it also contains challenges covering data security, equity, and unintended outcomes (Bevins & Howard, 2018). Designers should address gamification applications parallel with cultural norms and values (Armstrong & Landers, 2018). The application of BIM is expected to undergo technologically based transformations in the future through the adoption of virtual reality (VR), augmented reality (AR), and extended reality (XR) (Ng et al., 2023). These technologies and simulations through which reality gets mixed with the virtual world become possible and may extend creativity and collaboration in the design environments (Rubio-Tamayo et al., 2017; Schrom-Feiertag et al., 2020). VR, AR, and XR can be taught in interactive and sensory groups. Accordingly, one can use it as a tool that architects use to involve stakeholders in the decision-making process and transform their physical setting for better results according to their preferences and objectives (Jamei et al., 2006; Sanchez-Sepulveda et al., 2019). Therefore, gamification combined with BIM offers a groundbreaking approach for busier, holistic, and diversity-based design paradigms. By incorporating gamified approaches within immersive systems, designers can develop socially beneficial, ethically responsible spaces for creative authoring and design participation (Petrova et al., 2017). By bolstering the overall user experience, it elevates the standardized approach to design and enriches the design process for a better future.

2. PARTICIPATORY DESIGN IN THE DIGITAL ERA: LEVERAGING BIM FOR INCLUSIVE COLLABORATION

Specifically, about design-oriented techniques such as toolmaking (Gaver et al., 1999), analog workshops (Gaver, 2012), or design probes (Mattelmäki, 2006), participatory design shares commonalities primarily in this regard. It seems that the more the specialists also become part of the user set, the harder the line of authorship and the more difficult it is to design. Luck (2003, 2007) contends that the knowledge exchange and the seeking of more refined design perspectives can be facilitated and realized if designers draw upon the capabilities of the userbase to ensure good design guidance; explore potential design outcomes within the user's collaborative initiative; and enhance efficient interaction with users. Developments in digital technology have created a lot of tools and software that are being integrated into participatory design. Some examples of these tools and software are video games, simulations, virtual charrettes, and data visualization (Hou & Rios, 2003). This could occur using the application of digital technologies to enable users to experience actual living environments and design processes as they take place and appreciate some of the intricate social challenges that stem from their habitats and generate intelligent input (Al-Kodmany, 2001). For example, the use of technologies like virtual and augmented reality, extended reality, gamification, and building information modeling, can all be leveraged to create more engaging experiences. BIM environments can be additional to consumer engagement or peer decision-making and collaboration in design contexts and attract people who are uncomfortable about hand drawing and handcrafting to express themselves through interactive digital interfaces exploring the city appreciation. Both the users and the stakeholders can engage in it actively and providing preliminary response incentives to increase engagement, could enhance user experience. The National Institute of Building Sciences (Eastman et al., 2011) has a better description for BIM as "an integrated planning, design, construction, and operation process using a digital representation of the physical and functional properties of each building form in a computable object model with life cycle support." Eastman (2011) on the other hand, defines BIM as a modeling technology and related set of processes to produce, and exchange, which not only refers to building models but can also refer to other defined models of engineered systems such as the stages in production and the stages along the project lifecycle. BIM allows all important design decisions to be made digitally at the working drawing stage before the start of actual construction. This raises the level of confidence in every aspect of the project, including goals, sustainability, quality, cost, and timeline. The impact of BIM on design is noticeable at every stage of the building process. For instance, it facilitates integration and feedback for early conceptual design decisions (Elghaish and Abrishami, 2020). Energy efficiency standards are also incorporated at the design stage (Beazley et al., 2017; Jalaei et al., 2020). Finally, it evaluates a variety of construction alternatives' inherent environmental impacts (Röck et al., 2018; Rezaei et al., 2019). Construction-level modeling, which includes requirements, specifications, and cost estimation, is the initial step, according to Sadeghi et al. (2019) and Wang et al. (2017). Next is the support for new information workflows and the integration of engineering services. The construction of the collaborative design integration is complete. To evaluate different design possibilities and optimize design performance, construction BIM aims to replicate construction project processes and tasks (Eastman et al., 2011). As a result, BIM is one of the digital tools for simulating virtual environments associated with infrastructure, building, and design projects (Sanchez et al., 2022). In addition to increasing user experience by enhancing users' engagement with 3D models, it can also improve participatory design within immersive settings and produce more productive schematics and construction design drawings for new building renovation works (Kapogiannis et al., 2020). There hasn't been much research done on user-3D model interactions, despite evidence that suggests gamification techniques could be added to 3D modeling software platforms to increase user engagement (Kapogiannis, 2020). A framework that enables people to create immersive environments using VR devices like Oculus Rift, for example, could be developed by combining gamified BIM with participatory design. Wearing AR glasses like HoloLens, users would walk through architectural designs while holding controllers that would allow them to interact with various building components represented by XR objects displayed around construction sites.

3. INTEGRATING GAMIFICATION WITH BIM FOR ENHANCING PARTICIPATORY DESIGN

The meaning given to gamification is the incorporation of design elements from games into non-game environments to motivate and engage people (Selin et al.,2019; Zichermann and Cunningham, 2011). Involved experiences for individuals should have gaming features in them and this means that they must become part of our everyday life systems even outside sports activities. "Applying game mechanics, aesthetics, and game thinking to engage people, motivate action, promote learning, and solve problems" is one of the ways how Kapp (2012:10) defined gamification. The basis of gamification is the Human-Computer interface theory combined with theories related to incentives. According to Armstrong & Landers (2018) using digital or analog means of presenting these features involves referring to them as games while we talk about applying structural design patterns and concepts for enhancing employees' involvement in workplaces (Bevins and Howard, 2018). This new tactic becomes valuable under high-stakes conditions since it allows users to make comparisons by choosing among alternatives easily which could not be possible if they were only described in words that may vary greatly based on different interpretations given by each person (Pham & Bui, 2023). In the article, Koivisto and Hamari (2019) defined gamification as an approach to design that seeks to make systems and services more enjoyable through "game-like" experiences or by borrowing design elements from games. They argue that gamification is used in marketing, health, and education among other fields to enhance user participation (Hanus & Fox 2015; Hassan & Hamari 2020; Hofacker et al. 2016). This has led to organizations both in the public and private sectors adopting gamification together with smart technology as a way of raising the levels of engagement with their audiences. According to Deterding et al. (2011), gamification may be described as an umbrella term referring loosely to the use of video game mechanics and elements outside the gaming context to improve user experience (UX) and increase user engagement with the system. In the construction industry, after Building Information Modelling (BIM) was invented along with digital simulations and virtual environments, there emerged methodologies grounded on digitization such as gamifying work processes by utilizing game engine settings for simulating different scenarios. Historically speaking game-based technologies were mainly used within the construction sector for purposes like training workers or providing clients with alternative ways through which they could experience designs visually (De Marco 2022). The gaming engines' increased compatibility with some well-known BIM systems like Unity 3D has also caused a rise in the popularity of merging ideas between these two industries to facilitate realistic environments in video games (De Marco, 2022). Gamification can be done at different project levels i.e., design, build and use. It enhances traditional architectural software by providing immersive experiences, fostering collaboration, enhancing spatial understanding as well as stimulating creativity during the design process (Hamari et al., 2014; Hakak et al., 2019). According to Potseluyko et al. (2022), using a game-like platform alongside BIM may simplify data transfer to a client hence making them more satisfied and leading to increased sales. To improve the collaborative design process, it is necessary to reach out to users, interact with them, and sustain such engagement over time (Ingvarsson et al., 2023). The project will benefit greatly from the active involvement of participants who may introduce immersive worlds or include people who would not have been brought on board otherwise. This is part of gamification which "gets a person's attention and keeps it" as defined by Kapp (2012:11). It appears that gamification is important from an engagement perspective and designing spaces that can be inhabited by local actors requires involvement (Heravi et al., 2015). When participatory design first used elements of game design (Deterding et al., 2011), it became known as gamification, a concept that is defined by applying competitive challenges and rewards to alter conduct as well as increase involvement (Sanders, 2000; Brandt & Messeter, 2004). Gaming elements can stimulate motivation, interest, and concentration among people more effectively than any other form of teaching aid would do so alone (Leite et al., 2016). Leite et al. (2016) further posit that gamifying tasks makes them less boring or difficult for individuals while at the same time fostering cooperation and social interaction through shared fun experiences. Such an approach has consistently proven successful at boosting staff morale, commitment levels, and overall job performance across various types of organizations (Oke et al., 2023). And Kapogiannis et al., (2020) did thematic analysis. End-users have reported that they were able to enhance their coordination, communication, discussion, and suggestions. Kapogiannis and Sherratt (2018) attributed it to a "collaborative culture." Gamification paired with BIM integration can increase design comprehension. Participants might work together or against each other in other groups or teams for shared objectives. As a result, a sense of community is built leading people to assist each other achieve their goals (Feng et al., 2022; Xiao, 2022). Instead of using BIM alone, immersive spaces can be created through gamification technologies in addition to participatory design. During collaborative design processes, these systems have virtual attributes designed to make shared applications applicable. According to Sanchez et al. (2022), "gamified data model within BIM could offer various capabilities and simulations which can also improve the user experience while giving more detailed design information as well." There are many contexts and design problems that may be helpful by using these strategies like Selin and Rossi (2020). When applied to certain results, it can reinforce results popular among stakeholders and end users, promote the essence of teamwork, accelerate the design phase, optimize the experience of the users, and increase the level of inclusion, creativity, and innovation. The embracing of virtual, augmented, and extended reality (VR, AR, and XR) technology in business prognoses future trends and radical innovations. If designers wish to meet users' requirements, the solution is an example of an immersive place; anyone capable of engaging in the designing or building process can witness virtual environments and design engaging places (Petrova et al., 2017).

3.1. Future Directions and Developments Through VR, AR, and XR

The traditional use of VR, AR, and XR has proposed a transformative shift in architectural and urban design as stakeholders can be involved in the design and planning processes (Jamei et al., 2006; Sanchez-Sepulveda et al., 2019). Traditionally, architecture and urban planning involve people through conventional consultations, however, integrated design can engage, empower, and enable people and end-users to develop architectural and urban settings (Nabatchi et al., 2015; Wates, 2014). The adoption of VR, AR, and XR in participatory designs presents opportunities for engaging users in design proposal discussions and implementation through visually concrete and interactive environments (Schrom-Feiertag et al., 2020; Rubio-Tamayo et al., 2017). This also could be a result of advancements in technology and an increase in the compatibility of game engines that allows for more research to be done with exploring XR for BIM in recent years (Ng et al., 2023). More and more decision-makers integrate virtual reality into participatory design for architecture and urban design, asserting the need to assess the effectiveness of different forms of VR technology, BIM, and gamification in particular, for a successful and engaging participation as well as overall performance of the design process (Ehab et al., 2023). These technologies can support the co-designing of built environments through different parties and actors creating, planning, designing, and interactively visualizing. How it is beneficial or disadvantageous to implement gamification in BIM, and how it is possible to apply VR, AR, and XR to design realistic environments are also worth considering, as well as the opportunities and prospective but also together with the limitations and ethical challenges. Examples of gamification within BIM have been discussed in the literature, such as the study by Jamei et al. (2006), where virtual reality (VR) was used to engage stakeholders in a participatory design process. Another example is provided by Sanchez-Sepulveda et al. (2019), who explored the use of augmented reality (AR) in real-time visualization of design options, allowing for immediate stakeholder feedback and adjustments within the BIM model.

3.2. Exploration of BIM and Gamification Integration: An Analysis of Tools

BIM and gamification characteristics provide on the one hand the benefits of each approach to optimize project management, teamwork, and productivity enhancement tools in the construction field on the other hand. This section shares insights on how BIM and gamification can be integrated, examples of technologies, advantages and limitations, cost considerations, and key aspects when implementing this combination.

It ought to be noted that not only has the utilization of gamification and BIM come a long way since their integration in addressing the construction industry challenges in cooperation and engagement but has also delivered intelligent solutions to boost interaction and productivity. The above technologies reveal how the application of gamification in the BIM traditional software could enhance the usability and interactive features of the systems (Table 1). However, these technologies pose certain challenges that accompany them and require further investigation and practice to address in additional studies and projects.

Strengths:

- Enhanced User Engagement: Gamified features like rewards, immersive experiences, and progress tracking keep users engaged and motivated throughout the process.
- Improved Collaboration: Project stakeholders are encouraged to communicate and work together more through tools like Synchro and BIM 360.

Software	Advantages	Disadvantages	Price	Key Elements
BIM 360: A tool that developed by Autodesk for project tracking and performance visualizing that employs gamification techniques to foster engagement and enhance productivity.	It provides thorough tracking and visualization, strengthens accountability and motivation, boosts teamwork, and connects effectively with other Autodesk products.	May be difficult to set up, need a lot of training, and cost more for all features.	Enterprise pricing is available upon request, with starting prices for each user being $480 annually.	Dashboards, document management, issue tracking, award programs, and progress monitoring.
Synchro: As a conceptual utility used in gamifying construction sequences and improving collaboration and planning and currently in its fourth dimensionality, a 4D BIM program.	Increases cooperation, boosts planning and scheduling, detects any problems early, and visualizes the steps involved in building.	High learning curve, potentially costly, and necessitates large data intake.	The annual cost of licensing is roughly $2,000 per user.	Collaborative platform, schedule optimization, problem visualization, and 4D simulation.
Enscape: One of the most basic BIM plugins which makes BIM models for real-time rendering, and virtual reality.	Real-time rendering, immersive virtual reality experiences, enhanced design comprehension, easier client presentations, and early design flaw detection.	Requires VR-compatible gear, may call for a large amount of processing power, and has a higher initial hardware cost.	Begins at $39 per user, each month.	Virtual reality tours, real-time rendering, design representation, and client presentation tools.
BIMobject: There is a platform that has assumed gaming elements with the intent of encouraging people to download and apply BIM objects.	Enhances user interaction, encourages heavy usage of BIM components, and interfaces with different BIM programs.	Not every user will find gamified features appealing, and for optimal benefit, active engagement is required.	Basic access is free, while premium features have a bespoke price.	User awards, accomplishment badges, leaderboards, and a large library of BIM objects.
Buildertrend: One example of a project management program which is used for the incorporation of gamification into tasks, progress, and milestones.	Increases productivity and increases user engagement with processes, visual progress tracking, and task completion reward systems.	It takes time to set up and learn, can be overwhelming for first-time users, and may cost extra for advanced capabilities.	Core features have a monthly pricing of $99, but advanced options come at an extra expense.	Gamification of tasks, visual progress dashboards, tracking of milestones, and user rewards.

Table 1: Comparison of Gamification-Enhanced BIM Softwares.

- **Efficiency and Productivity:** Tools like Buildertrend and BIMobject enhance project management processes, increasing productivity and efficiency.

Weaknesses:

- **High Learning Curve:** Many of these technologies can be tricky to set up and use correctly, and they sometimes call for a lot of training.

- **Cost:** For smaller organizations, the upfront and ongoing costs of these products may be prohibitive.
- **Compatibility and Integration:** Ensuring compatibility with current systems and integrating various tools may pose challenges and require a significant amount of time.

Suggested Guideline/Pipeline:

Based on the literature, the following guideline/pipeline could be used as a recommendation for gamification integration with BIM in participatory design:

- **First Stakeholder Engagement:** Talking about the objectives of the project and creating a participatory framework (Snyder, 2019).
- **Gamified Design Sessions:** Including stakeholders in the usage of VR/AR tools (Sanchez-Sepulveda et al., 2019).
- **Continuous Feedback Loop:** Sharpening the study by placing a feedback system (Hou & Rios, 2003).
- **Final Review and Adjustments:** Improving the design utilizing the information and understanding gained from the gamified sessions (Kapogiannis & Sherratt, 2018).

3.3. Impacts and Benefits

Better judgments are taken, more effective and efficient problem-solving strategies are applied, design alterations are enhanced, and presentation visual quality is increased when these technologies are used in the design process. These technologies have the potential to improve user experiences, offer collaborative design, and interoperability of design and delivery processes, and support various design and building simulations. They can also support information and data visualization, team coordination and collaboration, process monitoring and control, and different designs (Alizadehsalehi and Yitmen, 2021). As a result, immersive spaces are promoted, the project's life cycle is shortened, and the overall cost is reduced. This is accomplished through better planning, more efficient use of resources, and the development of materials, processes, and resources. These technologies are well known for helping professionals and clients engage in more fruitful ways, and game technologies are successful in helping scientists and professionals solve problems. Furthermore, its application reduces the inefficiencies caused by data and information overload, improving information intake and project understanding. Overall labor costs and project length can be reduced by reducing errors and rework and improving time management (Delgado et al., 2020; Rahimian et al., 2019; Guray and Kismet, 2022). The power of game technology to promote more fruitful interactions between professionals and clients is widely acknowledged. They are also helpful in resolving business and scientific problems. They can be very helpful in decreasing the cognitive workload of workers during various building and assembly tasks and in decreasing the amount of time spent on building component selection and assembly processes and operations by augmenting images and the ambient environment illustrated in the relevant devices (Jetter et al., 2018; Hou et al., 2015; Oke and Arowoiya, 2021). While some studies focused on the use of XR technologies in the project's conceptual stages, others were mainly concerned with how to set up the workstation during construction (Potseluyko et al., 2022). According to Hou et al. (2015:3), using XR during construction and assembly tasks that provide dimension comparison and position determination can greatly reduce the amount of time needed for component selection and assembly as well as effectively reduce assembly errors. Making use of this technology in the design and construction phases can improve information retrieval, collaboration, and communication between various technologies and human and guided channels. By integrating virtual mediums into actual surroundings and imitating prototypes convincingly in real scenarios, workers can obtain valuable knowledge. Employees can see their immediate surroundings and the task at hand more clearly as a result. More precisely, by reducing the amount of time required for task completion, search and reading times, errors and reworks, and physical demands like head and eye movements and mental transformation that are necessary for building and assembly tasks, the use of XR in building tasks and processes improves the productivity/efficiency of the project overall. One way to highlight the main advantage of implementing XR in construction processes is that it will lessen the cognitive burden on employees. As a result, there is a reduction in the overall resource and embodied energy waste, project time and budget, and all the above (Kwiatek et al., 2019; Jetter et al., 2018; Wang et al., 2016; Meki and Lemieux, 2014; Chen and Xue, 2020). Therefore, XR technology can drastically increase the efficiency of the design and construction industries by reducing the project's overall cost and the amount of time spent on it. What matters more, though, is that they increase the initiative's sustainability. Reducing the amount of labor, rework, energy, and resources used in a project can help lower the carbon footprint and pollution (Delgado et al., 2020; Hajirasouli et al., 2021; Lamptey et al., 2021). Human-Computer Interaction (HCI) has been improved, the end-user experience has been enhanced, and environments have been improved through the integration of technologies through BIM with gamification and Virtual, Augmented, and Extended Reality Technologies, according to research by Kapogiannis et al. (2020) and Stakeholder communications are also improved in small scale constructions and developments.

3.4. Limitations and Challenges

However, promising areas for further investigation of the potential negative effects of employing these technologies and their plugins in BIM and the level of user engagement and participation in designing the building have been identified (Yu et al., 2022; Safikhani et al., 2022). While VR plugins can enrich visualization, it remains disputable how effective they can be for the development of interactive participatory models and for creating engagement (Davidson et al., 2020; Huang et al., 2019). Because plugins have little user interaction, further research is needed to determine how best to apply participatory design, especially regarding stakeholder engagement and involvement.

3.5. Ethical Considerations

Thinking over the problem of using different forms of virtual games and calling it gamification in the formal business world, then the question of participant exposure to the risk of being exploited arises (Leite et al., 2023). Ethics in the context of this work done by Paul and Elder (2003) refers to a set of concepts and principles that help in identifying what conduct fosters or detracts sentient beings. The use of gamification in the workplace comes with some ethical issues and hence deserves some lending of the ear. The potentially negative effects of wrongdoing in gamification include the creation of competition between co-workers, which could potentially lead to demotivation of the workers if intrinsic motivational tools replace the external ones (Korn & Schmidt, 2015). From the study by Korn and Schmidt (2015) on gamification in the marketing field, this technique has been applied to screen and fire underperformers in organizations. Thus, it implies that while applying the concept of gamification, certain precautions should be taken to avoid the situation which can turn into a dangerous pressure cooker where the employees' positive emotional and social experiences at work could be overshadowed with negative shading, or into useful means for the change of the climate in the team and employees' engagement (Shahri et al., 2014). According to Thorpe and Roper (2019) in their study regarding ethics in marketing use of gamification, they put a stress point on the criteria utilized as the basis for defining the specific relating to social responsibility, honesty, and truthfulness which all participants must follow. We can also argue that strictly speaking, people who advocate gamification are not interested in inflicting physical, let alone psychological, pain upon their fellow man. Chou (2015) states that for a gamified system to be considered ethical, it needs to fulfill two essential requirements: first, it is necessary to inform completely about the purpose of such functioning; secondly, the user should agree with the given kind of service. While it is significant that Marczewski (2017) stressed the importance of ethical aspects to be taken into concern when designing gamified systems, it is important to see that the two pillars of ethical issues in gamification are Transparency and Permission. To elaborate on the ethical issues surrounding the gamification of education, O'Sullivan et al. (2021) argue there is a need for moderation of aspects that may tactfully invite manipulation leading to the abuse of the tool. As per the ethical implications of engaging customers through gamification in interactive marketing, Al-Msallam et al. (2023) pointed out that it is high time to be significantly applied to avoid negative outcomes. Conversely, Kim (2015) in the analysis of misevaluation, seeks to identify the moral strategies that the ''users'' are exploited or manipulated, and the author strives to protect the ''user'' autonomy and well-being. Drawing from their literature on ethical objectives of gamefulness in healthcare, Coelho and Reis (2021) further make a big emphasis on the significance of stakeholder engagement to enhance moral conduct. There is presented a detailed overview of gamification ethics by Hyrynsalmi et al. (2018) who state that moral challenges are a critical factor in designing and implementing gameful systems. The identification of participatory design with game-centered design raises questions on various ethical concerns linked with data acquisition, protection, and tracking. It is not unusual for gamified elements to rely on sophisticated data acquisition mechanisms to acquire data and patterns from the users to achieve increased levels of user engagement and active participation. But these are procedures that require additional careful consideration of the ethical consequences. Since gamification involves making users engage in positive behaviors, they must be tracked to revisit the same action. While such data collection can increase efficiency and individualization, concerns arise regarding consent, transparency, and potential discretionary use. While there are benefits, the rights associated with participants, including their privacy, may be compromised if users are not always fully aware of how much data is being collected or used (Marreiros et al., 2016). In addition, the collection and analysis of personal information and data make individuals more susceptible to discrimination and manipulation if proper measures are not implemented. Additional ethical issues come to light if the effectiveness of the created gamified systems includes such elements of control. Regardless of whether they are implicit or hidden, surveillance approaches can pose risks that undermine user liberty and create default suspicion. Besides, the intimidation perceived through surveillance may have feelings such as compliance and self-policing, which translates to a lack of genuine involvement and cooperation in participatory design processes. Hence, to reduce measurable threats and to sustain user trust, significant consideration must be provided to the rationale, proportionality, as well as perimeters of overseeing tactics. Concerning gamification, as well as participatory design, privacy, emerges as a critical concept not only because of the protection of data but individual freedom as well. These are theoretically excellent but practically perilous due to several factors such as the use of gamified systems and large data traffic, which inevitably raises the risk of violations of privacy and unauthorized access (Felt et al., 2016). Namely, when their data are shared without their permission or utilized for algorithmic profiling, people feel forced and endangered. The application of effective technical barriers, openness of the privacy rules, and user control solutions are the requirements for privacy preservation. Ethical concerns involving data gathering, surveillance, and privacy in gamification and participatory design, where the values of innovations are juxtaposed with accountability, bring out the importance of balancing the two. These principles can be realized by practitioners so that ethical engagement and cooperation are achieved effectively via priority given to the aspects of transparency, permission, and user-oriented empowerment. However, real, and continuous monitoring and discussion are required to address new ethical concerns and ensure that gamified systems maintain the foundational principles of justice, respect, and dignity.

4. CONCLUSION

In many aspects, it may be considered that the use of game design elements coupled with Building Information Modeling (BIM) becomes a transforming moment in today's design practices, it has the potential to become revolutionary in terms of creating immersive environments and fostering collaboration in team projects. By incorporating such mechanics into the learning and design process, resolution of the challenges, and decision-making in scenarios with the help of simulations, for example, stakeholders are enabled to engage in the practice of participatory design for diversity, creativity, and innovation. This collaborative approach stresses the processes for the design of the physical deliverable, fabrication, and construction that yield improved value for the client and the stakeholders, reduce project costs, and deliver optimum value. This is enhanced by tools like BIM 360, Dalux, Synchro, & Enscape, BIMobject, and Buildertrend. Extension of reality in VR, AR, and XR technologies enhances the complexity of design environments by reinforcing actual-like settings and concurrently helps stakeholders engage more due to combined reality and virtual reality experience. Nonetheless, the complex ideas about ethics on data protection, equality, and emergent consequences must be paid much attention in the construction of gamified BIM systems. Meanwhile, to fully realize the potential of gamified BIM environments, designers must be willing to apply changes in ethical approaches and technological advances to counter these challenges. This includes incorporating robust data protection measures for gamified interactions, ensuring data contributed by users is competent and that rewards coupled with punishment are balanced, and fundamentally eradicating unpredictable consequences by organizing detailed risk assessments and contingency measures. Engaging experts across a variety of fields to participate in design and technology decision-making can serve to provide insights and approaches for navigating the complex ethical realities of gamified BIM environments. Designers may fully capitalize on gamified BIM settings to construct convincing locations that would ultimately blend actual and digital worlds into a singular setting and could apply these concepts and practices to meet the different objectives and goals of every stakeholder involved. The reconnaissance of optimistically configured BIM settings could be realized through gradual improvements and organic innovation; the new paradigm of social, Integrated designs may well be on the horizon as BIM opens the door to including and enhancing the pleasures of pro-developmental creations and innovations.

Recommendations for Future Studies:

- User-Centric Design: The goal of future research should be to lower the complexity and learning curve of these technologies to make them easier to use.
- Cost-Benefit Analysis: To offer more precise Return on Investment (ROI) information, studies ought to assess how cost-effective certain solutions are in different project scenarios.
- Integration and Interoperability: It is possible to increase the usefulness and usability of various BIM and gamification solutions by creating standards for improved integration and interoperability.
- Ethical Considerations: To guarantee that these tools are used appropriately, it is imperative to conduct an ongoing examination of the ethical implications of gamification in professional settings.

Gamification and integration with Building Information Modeling (BIM) offer a practical solution to enhance collaboration and project management in the construction industry. Tools like BIM 360, Dalux, Synchro, Enscape, BIMobject, and Buildertrend demonstrate how incorporating gamified elements can boost user engagement, efficiency, and productivity. Although these technologies have many benefits, like enhanced productivity and a better user experience, there are drawbacks, like a somewhat steep learning curve and compatibility problems. To effectively benefit from this integration, user-centric design approaches such as participatory design must be prioritized in future studies and projects. It is crucial to involve end users in the development process, carry out exhaustive cost-benefit evaluations, guarantee seamless integration and interoperability, and handle persistent ethical issues. By addressing these issues, the construction sector may better stimulate innovation and enhance project outcomes by utilizing the benefits of BIM and gamification. It's critical to recognize that there are many moving parts involved in realizing the revolutionary potential of gamified BIM environments. It calls for an all-encompassing approach that considers technological innovation, ethical considerations, and interdisciplinary collaboration. Through cautious handling of these problems, designers might build a future in which immersive and participatory design methods enable stakeholders and mold the built environment to fulfill societal expectations.

Acknowledgments

I sincerely thank Assistant Professor Hasan Burak Cavka for all your help, advice, and insights while writing this research. His knowledge of BIM and VDC and dedication to supporting new ideas in the field have greatly influenced the ideas given here. His support has always motivated me, and I appreciate that I have had the chance to study under his guidance.

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