ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL

EXPLORING THE ROLE OF GAME MECHANICS IN GENERATING SPATIAL COMPOSITIONS: SNARIS CASE

M.Sc. THESIS

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ISTANBUL TEKNİK ÜNİVERSİTESİ ★ LİSANSÜSTÜ EĞİTİM ENSTİTÜSÜ

OYUN MEKANİKLERİNİN MEKANSAL KOMPOZİSYONLARIN OLUŞTURULMASINDAKİ ROLÜNÜN DEĞERLENDİRİLMESİ: SNARIS ÖRNEĞİ

YÜKSEK LİSANS TEZİ

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Ozan Can ÖZVATAN, a M.Sc. student of İTU Graduate School student ID 529201018, successfully defended the thesis entitled **"EXPLORING THE ROLE OF GAME MECHANICS IN GENERATING SPATIAL COMPOSITIONS: SNARIS CASE"**, which he prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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Date of Submission : 26 May 2023
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To the dark side of the force,

FOREWORD

This research allowed me to create a game called *Snaris*, which is the backbone of the research—many thanks to Ali Ersoy, who developed the game with great precision and speed. Also, I would like to express my sincere gratitude to my thesis advisor, Assoc. Prof. Dr. Sema Alaçam, for her patience, guidance, and motivation throughout this journey.

May 2023

Ozan ÖZVATAN
(Game Designer)

TABLE OF CONTENTS

Page

ABBREVIATIONS

AC	: Total area of unroofed closed spaces
AR	: Total area of the roof in the composition
AV	: Total area of roofed and unroofed closed spaces
BB	: Bounding box size
CC	: Number of closed spaces without a roof were created during a session
DB	: Distribution of blocks on various levels
LC	: Level count
RC	: Roof element count
RR	: Ratio of roof elements’ coverage in the entire composition
TB	: Total number of blocks used in the session
WV	: Height variation in a facade or wall
XY	: Birds-eye view horizontal and vertical sprawl ratio

LIST OF TABLES

LIST OF FIGURES

Page

EXPLORING THE ROLE OF GAME MECHANICS IN GENERATING SPATIAL COMPOSITIONS: SNARIS CASE

SUMMARY

As the world becomes increasingly digitized, the study of virtual environments and user's agency in it has emerged as an important field of research. Video games, in particular, serve as an influential subset of these digital spaces, presenting an array of dynamic, complex, and interactive worlds. These game-spaces are experienced by users regularly, and also raise interesting questions about human interaction, cognition, and experience within virtual realities.

In a game, the player acts as both the subject, engaging with the gaming system, and the object, receiving responses based on their input. Their actions and decisions are interwoven into a complex system of cause and effect, where each decision leads to a change in the state of the virtual environment, thereby influencing their subsequent actions. This cyclical process organizes all decisions made during the gaming session, and the game space emerges as a result.

This research is about user interaction with virtual spaces, exploring the impact of game mechanics -specifically risk and reward mechanics- on the player's agency in shaping the virtual environment, thus establishing a discussion on exploration at the intersection of game studies, architecture, and human-computer interaction.

More specifically, the goal of this research is to answer following questions: How does the involvement of risk and reward mechanics impact the spatial outcomes generated by participants using a 3D puzzle game? In which ways do the risk and reward mechanics affect the player's role in shaping virtual spaces? What is the impact of more challenging situations on the spatial composition in a virtual environment? How do software limitations influence the generation of spatial elements?

To investigate the impact of risk and reward mechanics on generating spatial outcomes, we designed and developed a two-state digital application called Snaris, a 3d puzzle game, in which we can isolate various mechanics in two distinct modes. We compared the spatial compositions created under these distinct conditions by comparing scenes created in Play Mode which harbors risk and reward mechanics with scenes created in Build Mode, which lacks said mechanics.

We proposed a method for qualitatively assessing spatial features of scenes created in Snaris. This method employs 12 criteria for evaluating unique 3D spatial compositions generated by the application. We collected data by conducting playtests with 20 participants with each submitting a scene from both modes of application.

We observed that where the risk and reward mechanics exist, participants were usually more preoccupied to be able to shape the spatial outcome deliberately. Thus, creating more random and incoherent structures. On the other hand, the absence of risk and reward mechanics and a clear, unobstructed game environment allowed players to engage in unconventional actions, and create familiar topologies, in a setting that encourages exploration and experimentation throughout the session.

OYUN MEKANİKLERİNİN MEKANSAL KOMPOZİSYONLARIN OLUŞTURULMASINDAKİ ROLÜNÜN DEĞERLENDİRİLMESİ: SNARIS ÖRNEĞİ

ÖZET

Dünya giderek daha fazla dijitalleşirken, sanal ortamların ve kullanıcıların bu alanlardaki etkinliğinin incelenmesi önemli bir araştırma alanı olarak ortaya çıkmıştır. Özellikle video oyunları, bu dijital alanların önemli bir alt kümesi olarak hizmet verir ve dinamik, karmaşık ve etkileşimli dünyaların bir dizisini sunar. Bu oyun mekanları, sürekli olarak kullanıcılar tarafından deneyimlenir ve aynı zamanda bu sanal mekanların içindeki insan etkileşimi, bilişsel süreçler ve kullanıcı deneyimi hakkında ilginç soruları gündeme getirir.

Bir oyunda oyuncu, oyun sistemine katılan özne olarak hareket ederken, girdilerine dayalı yanıtlar alarak nesne olarak da hareket eder. Oyuncunun eylemleri ve kararları, neden-sonuç ilişkisi içinde karmaşık bir etkileşim ağına entegre edilir, her karar sanal mekanın durumunda bir değişikliğe yol açar ve bu nedenle sonraki eylemlerini etkiler. Bu döngüsel süreç, oyun oynama sırasında alınan tüm kararları düzenler ve oyun mekanı sonuç olarak kendini sürekli tekrar üretir.

Bu tez, oyun mekanikleri ile sanal ortam oluşturma ve modifikasyon arasındaki karmaşık dinamikleri inceler ve böylece oyun çalışmaları, mimarlık ve insan-bilgisayar etkileşimi gibi alanların kesişiminde bulunur.

Bu çalışma, risk ve kazanç kurallar seti olarak da tanımlanabilecek bir dizi oyun mekaniklerinin asıl belirleyici olduğu oyun modu ile bu tür kısıtlamaların olmadığı bir inşa modunu yan yana getirerek, bu farklı koşullar altında oluşturulan ortamları karşılaştırır ve kullanıcının bu süreçteki rolünü araştır. Böyle bir yaklaşım, oyun mekaniklerinin sanal ortamları nasıl şekillendirdiğine dair anlayışımızı genişletir ve oyun ve tasarım arasındaki geleneksel sınırları sorgular.

Bu çalışmanın ana omurgasını oluşturan araştırma soruları aşağıdaki gibi özetlenebilir:

• Risk ve ödül mekaniklerinin 3D bulmaca oyunu kullanarak katılımcılar tarafından üretilen mekansal sonuçlar üzerindeki etkisi nedir?

• Risk ve ödül mekanikleri, oyuncunun sanal mekanları şekillendirme rolünü hangi yollarla etkiler?

• Oyun sırasında karşılaşılan zorlu durumların sanal ortamdaki mekansal kompozisyonun üretimi üzerindeki etkisi nedir?

• Yazılımsal kısıtlamalar mekansal öğelerin oluşturulmasını nasıl etkiler?

Söz konusu araştırma soruları ışığında risk ve ödül mekaniklerinin mekansal sonuçların oluşturulmasına etkisini araştırmak için Snaris isimli 3D bulmaca oyunu tasarlandı ve geliştirildi. Bu uygulamanın iki farklı modunda çeşitli mekanikleri izole edebiliyoruz. Risk ve ödül mekaniklerini içeren Oyun modunda oluşturulan sahneleri, bu mekanikleri içermeyen İnşa modunda oluşturulan sahnelerle karşılaştırarak bu farklı koşullar altında oluşturulan mekansal kompozisyonları karşılaştırıldı. Bu

uygulama ile "playtest" yöntemini kullanarak elde edilen veri setini (her iki modda da bitmiş oyun sahneleri) nitelik bazlı bir metodoloji ile analiz edildi.

Bu çalışma, kullanıcının sanal mekanlarla olan ilişkisini anlamak için öncelikle teorik arka planı tartışarak başlar. Bu kısım, 3 ana direk üzerinde şekillenir:

1.Kullanıcının ve tüm oyun nesnelerinin tabi olduğu ve içinde bulunduğu sanal ortamlar: Mekanikler çerçevesinde kullanıcı ile oyun mekanı arasındaki tüm etkileşimin gerçekleştiği yer.

2.Kullanıcının sanal ortamla etkileşime geçmek için hangi araçlara sahip olduğu ve sanal ortamı yöneten kuralların ne olduğu (mekanikler).

3.Kullanıcının, bahsi geçen sanal ortamlar (1) ve bu ortamla etkileşime geçme çerçevesini (2) yönlendirmedeki rolü.

Sanal mekanlar ve uzamsal kompozisyonların tartışıldığı (1) alt başlığında öncelikle "sanallık" olgusu ele alınır ve "sanal" olanın dijitalden ibaret olmadığı öne sürülür. Daha sonra, onlarca yıldır aralıksız şekilde gelişen bilgi işleme kapatisenin doğurduğu oyunlardaki görsel ve işitsel sanal mekanlara odaklanılır ve literatürdeki sınıflama ve yerleşmiş argümanlara yer verilir.

Oyun mekaniklerinin sanal mekanların oluşumundaki etkisini anlamak için; (2) alt başlığında bu konudaki literatürdeki fikirlere yer verildi. Bu kısımda, genelde oyun geliştiricilerinin kurgulayıp kullanıcıların çoğunlukla pasif bir şekilde deneyimlediği "statik mekan" ve kullanıcıların, mekanın kurulumu ve kendi özdevinimini kontrol ettiği; bir başka deyişle, kendi kendini üreten özyinelemeli mekan (recursive space) kavramları tartışıldı. Daha sonra oyun mekaniklerinin mekansal kurguyu nasıl etki etkilediği ve tam tersi olan mekansal kurgunun oyunun oynanış biçimini nasıl değiştirdiğini anlamak için navigasyon, ilerleme, mekansal etkileşim, strateji, imtihanlar, naratif ve çoklu kişi konuları ele alındı. Yukarıda bahsi geçen mekansal etkileşim konusu, bu tez kapsamını daha çok ilgilendirdiği için bu kısım detaylandırılarak yapılabilir veya yıkılabilir çevre, oyun objeleri ile etkileşim, çevresel riskler ve bilmeceler gibi konular değerlendirildi. Bu kısım sonunda, bütün bu kategoriler dikkate alınarak piyasada yayınlanmış ve tanınan bir oyun seti belirlenerek özet bir inceleme yapıldı.

Kullanıcının sanal ortamdaki etkileşimi ve rolünün tartışıldığı (3) alt başlığında, kullanıcının oyunu oynayarak ve oyunun durumuna bağlı olarak aktif olarak karar vererek sanal ortamla etkileşime girdiği önermesi genişletilir: Kullanıcıdan gelen her türlü giriş, sanal bir ortamda durum değişikliğine neden olur ve bu değişiklik, oyuncunun karar vermesi için takip eden girişi oluşturur. Oynama esnasında alınan tüm kararların toplamı, bir bütün, bir kompozisyon veya diğer bir deyişle: bir özyinelemeli mekan oluşturur. Çok oyunculu yaratıcı oyunlar ise, oyuncuların aktif olarak yaratma sürecine katılmalarına izin vererek oyun dünyalarının şekillendir. Bu katılım, ortak yaratmayı mümkün kılan oyun özelliklerinin örnekler ve analizleri aracılığıyla incelenir. Oyunculara yaratıcı roller vererek, oyun dünyasını kendileri ve diğerleri için değiştirebilirler, oyun geliştiriciliği ve kullanıcı arasındaki çizgileri bulanıklaştırırlar. Bu yaklaşım, kullanıcılar arasında müşterek bir mekan oluşturmayı teşvik eder, oyuncular tarafından yönlendirilen hikayeler ve oyuncuların yaratıcılar haline geldiği sanal dünyalara yol açar. Bu ortak yaratma sürecini tanımlamak, oyunlardaki etkileşimli hikaye anlatısına taze bir bakış açısı sunar, kullanıcıların oyun dünyalarının ortaklaşa üretimi aracılığıyla hikayeleri ve sanal mekanları nasıl şekillendirdiğini ve oyun aracılığıyla geliştiricilik rolleri üstlendiğini vurgular.

Tezin üçüncü kısımda ise daha önce bahsi geçen Snaris uygulamasının kendisi ve araştırma metodolojisi detaylandırılır. Bu uygulamada, temel olarak kullanıcı üç boyutlu bir mekanda sürekli bir blok akışını yönlendirir ve böylece çeşitli yapılar, hacimler ve alanlar oluşur. Oyun sahnesi veya seviye olarak bilinen sanal mekan kurgusu, oyuncuların kasıtlı veya kazara eylemlerinden dinamik bir şekilde gelişir ve ortaya çıkar. Uygulama, rastgele kural setlerinin ve oyun mekaniklerinin etkisini gözlemlemeyi sağlayan iki ana moda sahiptir. İlk mod Oyun Modu'dur, bu modda risk ve kazanç kural setleri oturumu yönetirken, ikinci mod İnşa Modu'dur. İnşa Modunda, oyun alanı, kullanıcı etkileşimi ve kontrol şeması aynı kalır, tek fark bahsi geçen kural setlerinin olmamasıdır. Snaris, tek oyunculu bir 3B bulmaca oyunu türüne girer. Oyun becerileri, 3B mekansal algı, sezgi, gerçek zamanlı karar verme ve karmaşık alan ve perspektiflerin çözümlenmesi gibi çeşitli becerilerin geliştirilmesi ve kullanılmasını vurgular. Ayrıca, uygulama, oyun dışında alternatif kullanımlar sunar, kısıtlı olsa da, bir 3B eskiz ve modelleme aracı olarak hizmet edebilir, mekansal ilişkiler üzerine eğitimi kolaylaştırır ve mimari tasarıma oyunlaştırmayı entegre eder.

Yazar tarafından tasarlanan ve Ali Ersoy tarafından geliştirilen bu uygulamanın hedef ve amaçları tartışılır. Çalışmanın araştırma sorularına cevap verebilme yetisi incelenilir. Daha sonra uygulama tasarımı detaylıca açıklanır. Bu çalışmanın belkemiği olan fakat şu aşamada henüz prototip olarak tamamlanan uygulamanın kapsamı ve kısıtları değerlendirilir. Oyunun mekanikleri, kural seti ve sanal mekan kurgusuna ait prensip ve prosedürleri detaylandırılır. Daha sonra, uygulamanın tasarım ve geliştirme süreci paylaşılır. Snaris' in tasarım sürecinde ilham olan, çeşitli mekanikleri ile benzerlik gösteren Tetris (1984), Snake (1976), Volfied (1989), Minecraft (2011) ve daha önce yazar tarafından hazırlanmış 3dTetris uygulamalarını karşılaştırmalı olarak ele alır ve Snaris ile bu uygulamalar arasında bağlantılar kurulur. Sonraki kısımda ise Snaris' in geliştirme süreci ve tasarımda hedeflenen fakat teknik sebeplerle gerçekleştirilemeyen özelliklerine değinilmiştir.

Söz konusu uygulama ve nitelikleri tartışıldıktan sonra çalışmada kullanılacak metodolojiyi tartışmak için literatürde uzamsal kompozisyonları anlamlandırmak ve değerlendirmek için sıkça kullanılan bazı niceliksel (quantitative) yöntemlerden bahsedilir. Bunlar arasında hesaplamalı geometri, mekansal sözdizimi (space syntax), ajan tabanlı (agent based) modelleme, prosedürel üretme, entropi yöntemleri ve fraktal yöntemler bulunmaktadır. Daha sonra, bu araştırmanın belkemiğini oluşturan Snaris uygulaması tarafından oluşturulan özgün mekansal kompozisyonları değerlendirmek için kullanılacak olan yaklaşım olarak bulunan belirli özelliklere dayalı farklı bir niteliksel (qualitative) yöntem önerilmiştir. Bu yöntem, katılımcılar tarafından oluşturulan mekansal kompozisyonları analiz etmek ve değerlendirmek için 12 adet mekansal özelliğe dayalı kriterler önerir. Mekanın niteliklerini ölçme ve anlamlandırmaya yönelik bu kriterler detaylandırılır ve tartışılır.

Bu araştırmanın ana amacı, Snaris uygulamasının inşa modu ve oyun modu arasındaki tamamlanmış mekansal kompozisyonlarını karşılaştırmak ve analiz etmektir. Katılımcıların her 2 modda da oluşturduğu mekansal kurgular, veri toplama yöntemi olarak belirlenmiştir. Bu araştırma kapsamında tipik bir deney toplantısı, uygulamanın, amacının ve oyun kontrollerinin tanıtımıyla başlar ve ardından bir soru-cevap oturumu gelir. Katılımcılara, tercihlerine göre uygulamayı özgürce keşfetmek ve kullanmak için 15 dakika verilir. İlk 15 dakikanın ardından, hem oyun modunda hem de inşa modunda uygulamayı kullanmak için eşit 15 dakikalık zaman dilimleri ayrıldı, sürenin yaklaşık olarak eşit bir şekilde bölünmesi şartıyla sıranın esnek olması mümkün kılındı. Katılımcılar, her mod için tercih ettikleri son oyun sahnelerini seçme ve gönderme fırsatına sahiptiler. Oyun oturumlarından sonra, oyuncuların oyun deneyimleri hakkında bilgi edinmek için kısa bir mülakat yapıldı.

Dördüncü kısım ise söz konusu uygulama ile Playtest'ler sonucu elde edilen veriler ile gerçekleştirilen vaka çalışmasını konu alır. Bu kısımda Playtest'ler ile elde edilen veri ortaya konulur ve toplam 20 kişi ile uygulamanın her iki modunda da üretilen sahneler incelenir. Bu oyun sahneleri araştırmanın üçüncü kısmında belirtilen metodoloji aracılığıyla analiz edilir ve sonuçlar tartışılarak yorumlanır.

Bu araştırma sonucunda, risk ve kazanç kuralları, hemen her bir oyunun temel bir özelliği olmasının yanında, oyunları ve simülasyonları ayıran ayırt edici bir faktör olduğu belirtilir. Bu mekaniklerin varlığının, katılımcıları daha küçük, daha tutarsız ve daha rastgele kompozisyonlar oluşturmaya zorladığını gözlemledik. Söz konusu mekaniklerin varlığı, katılımcıların genellikle oluşacak sonuç mekan hakkında daha az farkındalığı olarak oynamasına neden oldu. Ayrıca bahsi geçen mekaniklerin olmadığı İnşa modunda katılımcıların daha özgürce mekan ürettiği, daha büyük ve alışılmadık kurgular yarattığı ve ürettikleri kompozisyonları kale, havuz gibi çeşitli inşai tipolojilere benzetme eğilimlerinde oldukları gözlemlendi.

1. INTRODUCTION

> The term 'intelligence amplification' seems applicable to our goal of augmenting the human intellect in that the entity to be produced will exhibit more of what can be called intelligence than an unaided human could; we will have amplified the intelligence of the human by organizing his intellectual capabilities into higher levels of synergistic structuring (Engelbart, 1962, p.25).

Engelbart discusses the concept of "augmenting human intellect," which involves increasing a person's capability to approach complex problems, comprehend them, and derive solutions. He argues that with the increasing complexity of society's problems, exploring ways to augment human intellect in an integrated system is essential. He outlines a conceptual framework for a research program aimed at improving human intellectual effectiveness, which involves considering the whole system of a human and his augmentation means as a set of interacting components. It gives an illustrative example of an augmented architect at work using computer-aided systems (1962).

Technology and its uses can shape the intellectual sphere of human interaction in previously unforeseen ways. To illustrate, let's explore the realm of video gaming. In this domain, a person's intellectual abilities are not just augmented through traditional learning means but also by dynamically interacting with the gaming environment, which challenges the player to solve problems, learn new abilities, and navigate through complex systems with varying degrees of abstraction. The influence of technology, in this case, manifests as the game mechanics and the designed -or user-generated- environment, creating a symbiotic relationship between the human intellect and the tools at its disposal.

Thus, the essence of this study is that game mechanics profoundly affect spatial compositions generated during gameplay or in virtual environments. How the environment is designed and structured can significantly affect player experiences, behaviors, and actions. Conversely, the player's perception and actions can also affect and reshape the virtual environment generated during a play session.

1.1 Purpose of Thesis

The evolving dynamics of digital gaming have placed a renewed focus on the player's role within virtual environments. This study is grounded on the premise that in a game, the player acts as both the subject, engaging with the gaming system, and the object, receiving responses based on their input. Their actions and decisions are interwoven into a complex system of cause and effect, where each decision leads to a change in the state of the virtual environment, thereby influencing their subsequent actions. This cyclical process uniquely organizes all decisions made during the gaming session. This research is about user interaction with virtual spaces, exploring the impact of game mechanics (specifically risk and reward mechanics) on the player's agency in shaping the virtual environment.

1.2 Research Questions

- How does the involvement of risk and reward mechanics impact the spatial outcomes generated by participants using a 3D puzzle game?
- In which ways do the risk and reward mechanics affect the player's role in shaping virtual spaces?
- What is the impact of more challenging situations on the spatial composition in a virtual environment?
- How do software limitations influence the generation of spatial elements?

1.3 Motivation

The growing interest in virtual environments, particularly in immersive virtual spaces, has sparked increased attention toward understanding the dynamics of a player's agency and role. Research in this domain is essential as it offers insight into the interplay of gaming systems, player choices, and in-game outcomes. Unraveling these elements sheds light on players' behavior, gaming motivations, and the psychological impacts that these virtual environments may have. It also offers critical feedback for game developers, allowing them to fine-tune their designs, promote player engagement, and enhance the overall gaming experience. Researchers can better understand human-computer interaction by investigating players' agency and role, thereby contributing to the rapidly evolving field of immersion in virtual environments.

According to Chertoff et al., users' virtual experience results from multiple factors working together. These factors include external influences that set the context for a virtual space, such as the physical environment and the tasks at hand. Consequently, the physical environment creates a sense of immersion, while the task environment can lead to a sense of involvement (2010). However, the virtual environment is not static; instead, it is characterized by recursion, often called "recursive space." According to Wood, gamers and the game mutually shape the gaming experience. The outcome of gameplay is influenced by both gamers and the game, forming a recursive relationship between the game's and the gamer's states and actions. While the player generates space, they acknowledge that their actions and decisions have consequences, shaping the virtual environment and influencing subsequent actions (2012).

Thus, research in this field of understanding the player’s involvement in generating space is essential. It sheds light on the virtual environments in digital games and other innumerable applications that users deal with in virtual environments, whether 2D or 3D. To understand the player's agency while generating and manipulating space, we must first evaluate these spaces -whether qualitatively or quantitively-.

To achieve the mentioned goals and answer research questions, the author designed an application called Snaris. After the initial design phase of Snaris, the author/designer collaborated with Ali Ersoy, who programmed the application in Unreal Engine 5 (the application's design and development will be elaborated in Chapter 3.1). Along with being a testbench for this research, the application is also a fun and engaging game.

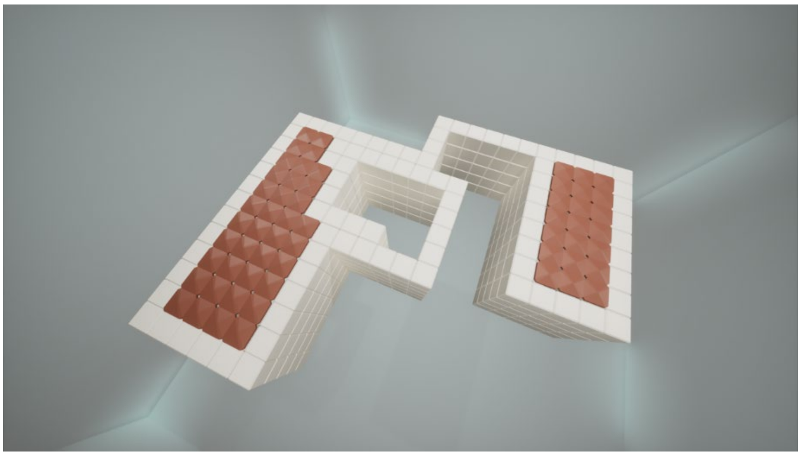

Figure 1.1 : A scene created in Build Mode in Snaris in the test session #20.

1.4 Research Method

Quantitative evaluation of spatial compositions has been explored through numerous techniques, which include computational geometry, spatial syntax, agent-based modeling, procedural generation, entropy methods, and fractal methods. (Dursun, 2007; Güzelci & Şener, 2019; Liang et al., 2012). Though distinct in their mechanisms, each approach strives to measure, analyze, and predict spatial properties and their effects on users' behavior and experience. Computational approaches are typically employed to measure spatial characteristics such as area, distance, and proximity. Spatial syntax assists in understanding the relational aspects of spaces, exploring accessibility and visibility attributes. Agent-based modeling focuses on simulating autonomous agents' interaction with the environment, predicting spatial usage patterns. Procedural analysis uses algorithmic logic to produce randomized yet rule-based virtual spaces. Entropy method for design evaluation, derived from information theory, is employed to gauge the complexity and unpredictability within a spatial system, providing insights into its informational richness and variety. This aids in understanding how users may interact with or perceive these spaces. Fractal methods, on the other hand, investigate the geometric complexity of spaces and geometric similarity across different scales. Such analysis assists in determining the intricacy and intricateness of spatial patterns in virtual environments.

Figure 1.2 : Another scene created in Play Mode by the same participant shown in Figure 1.1.

Different from the aforementioned methods, this study employs a qualitative method. This method focuses on the extraction of qualitative characteristics of a virtual space through qualitative evaluation of its properties. This approach offers a degree of flexibility and is particularly useful when dealing with specific types of virtual spaces, such as those with solely organic or block-based geometries.

To investigate our research goals, a case study application was proposed. In this case study, we will investigate how the role of players and risk and reward mechanics can impact virtual spaces in interactive digital applications. To measure the impact of said mechanics, a 3D puzzle game called Snaris was designed and developed as an experiment apparatus to investigate the research goals. The application harbors two distinct modes of operation called Build Mode and Play Mode, in which we can isolate the existence of risk and reward mechanics without interfering with any other dynamics, such as the control scheme.

The data collection method is "playtesting" using both modes of Snaris. The playtests, in the scope of this research, are a controlled experiment setup in two distinct modes: Play Mode and Build Mode. Play Mode incorporates a set of risk and reward mechanics influenced by several games, while Build Mode allows players to generate and organize space without any game rulesets. The gameplay and visuals remain the same throughout the application except for the additional mechanics employed in Play Mode.

At the beginning of a playtest, the participant received an introduction to the application, including its purpose and game controls. A question-and-answer session followed to address any inquiries. Subsequently, participants were given 15 minutes of unrestricted exploration and utilization of the application based on their preferences. After this initial period, players were allocated equal 15-minute time slots to play the game in both Play and Build Modes. The order of playing these modes was flexible as long as participants roughly divided the designated time equally between them. Finally, participants could choose and submit their preferred end-game scene for each mode. A concise interview was conducted to gather insights into the overall experience of the user. The author re-created the submitted end-game files with the "analyze scene" function in Snaris to evaluate the collected data (see Chapter 4.2).

The data gathered from playtests are qualitatively evaluated using a set of clear-cut criteria for this application and research. Considering the limitations and specific characteristics of the scenes generated in Snaris, the author evaluated the end-game scenes using mainly a qualitative approach. With this method, we will analyze the spatial compositions by answering a set of criteria. Answers to the application-specific questions (which will be elaborated on later in Chapter 3.2) will be quantifiable to make meaningful deductions from this research. Lastly, in Chapter 4.2 and 4.3, we will examine the collected data and make deductions. Throughout this thesis, all the tables shown are created by the author.

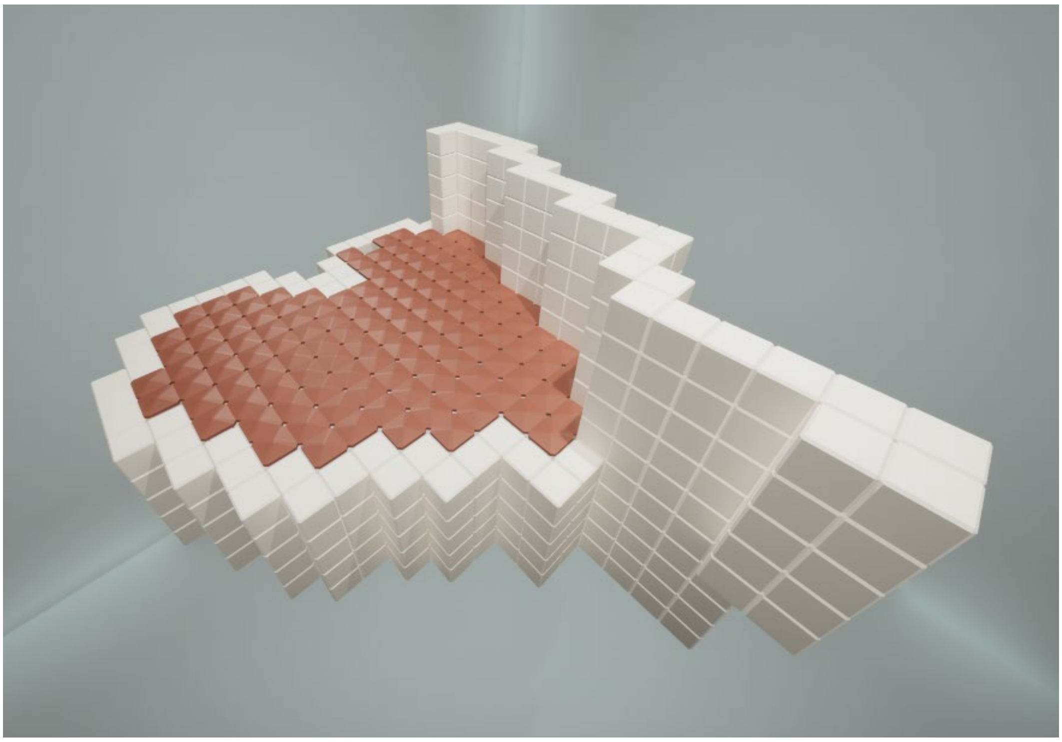

Figure 1.2 : A scene created in Build Mode in Snaris. In Build Mode, due to unimpeded and clear nature of virtual environment, playtesting participants sometimes chose to create familiar shapes and structures.

2. THEORETICAL BACKGROUND

This study is grounded on three main pillars:

1. Virtual environments that the player and all game objects are subjected to and contained: Where all the interaction between the user and game space happens (within the framework of game mechanics).
2. Tools that the player/user must interact with the virtual environment (1) and mechanics that govern the shaping of the virtual environment.
3. Player's agency in navigating in virtual environments (1) and the mechanics of interaction with the space (2).

In this chapter, we will investigate these subjects in detail, which will lay the groundwork for this research.

2.1 Virtual Environments & Spatial Composition

2.1.1 The context of virtual

The term "virtual" often gets conflated with "digital", primarily due to the prevalence of the term in technology and internet-based contexts. However, it's essential to consider that "virtual" has a broader meaning that encompasses more than just the digital realm.

The term "virtual" denotes something that has the essence or effect of a particular thing without being that thing. It can be linked with anything that exists in effect or result, even if not in fact or physical form. So, while the digital world is a prominent example of something virtual, it's not the only one.

Friedberg examines the meaning and history of the term "virtual" and argues that it should not be limited to only electronically mediated or digitally produced images and experiences. The term "virtual" is a substitute for the material and refers to the register of representation itself, with representation that can be either "simulacra" or directly "mimetic". A virtual image is an immaterial form that is functionally but not effectively material, with its own liminal materiality of a different ontological order. The term "virtual" was used to describe an image seen through a lens or a mirror, and both meanings imply a separate ontological register. The virtual image begins to have its own materiality even if it is of a different ontological order (2009, pp.7-12).

The concept of virtual extends far beyond the boundaries of digital gaming experiences. It encompasses various forms of virtual spaces and environments that exist in different domains of our lives. However, for convenience, this research will focus solely on the user's role in creating and shaping the virtual environments of games.

Therefore, by understanding the agency of the player and the effects of game mechanics on spatial generation, we might have a better idea of evaluating real-life perception.

In this manner, the scope of our research is limited to game spaces that also encompass real-life physical spaces because the line between the "virtual" and "real" has become increasingly blurred. For instance, we design buildings, devices, and other structures in virtual worlds, but they often manifest into tangible, real-world constructs. This phenomenon indicates a profound interaction and overlap between the digital and physical realms, creating an integrated system where enhancements in one often translate into advancements in the other. Thus, our investigation seeks to understand how digital augmentation affects human intellect and interaction within virtual environments and how these influences permeate our physical reality, transforming how we approach design and problem-solving in our everyday lives.

2.1.2 Virtual space in digital games

The evolution of computing power since the mid-last century has drastically improved the abilities and possibilities in the field of representation of virtual media. This allowed game designers to create increasingly complex audio-visual media that can also be interacted with.

In this context, spatial design of virtual environments in games becomes particularly intriguing. As our digital representations become more realistic and immersive, the importance of space in shaping gameplay and player experience becomes increasingly apparent. Spaces within a game are not just static backdrops but dynamic environments that players can interact with, manipulate, and navigate through, often directly influencing the player's experience and outcome of the game.

To step back and look at the game space theoretically: Schell argues that every game occurs within a specific space referred to as the "magic circle" of gameplay. This space defines the various locations within the game environment and how they relate to each other. When examining space as a game mechanic, we must remove all visual and aesthetic elements and focus solely on the abstract structure of the game's space. Describing these abstract game spaces does not have rigid rules, but in general, game spaces:

1. Can be either discrete (distinct and separate) or continuous (uninterrupted).
2. Have a certain number of dimensions.
3. Feature-bounded areas that may or may not be connected to each other (2008).

Each kind of virtual space, whether discrete or continuous, one-dimensional, or multidimensional, bounded or unbounded, brings unique dynamics to gameplay. They are not just geographical locales but platforms for interaction, challenge, exploration, and immersion. Understanding these spaces' abstract structures is crucial to harness their potential and continually elevate the gaming experience. As technology advances, the possibilities for these game spaces expand, redefining the boundaries of the "magic circle" and pushing the limits of our interactive, virtual experiences.

2.1.3 Spatial generation and composition in digital games

According to Nitsche et al., the type of game spaces can be broken down into four main categories:

- Designer-created spaces, in which the virtual game worlds are usually pre-modeled by game developers and are mostly passive and rigid. Players experiencing this type of virtual environment have no control over the world itself. Therefore, the interaction is limited to what game developers and mechanics offer.
- Random level generators in games like Diablo and Rogue create unique game spaces using predefined "level elements." While this feature adds replay value, it also limits player agency and variety in the game world. As a result, random

level generators fail to meet the second requirement for designing procedural game spaces as they do not involve the player in the level generation process.

- Player-created spaces: Games such as Half-Life allow players to generate game spaces through mods and customizations, which can significantly extend the game's life cycle and design range. This player-created content relies on external editors, and players cannot generate content while playing. In contrast, the game Second Life offers a hybrid approach, allowing players to shape and code their own spaces within the game world. However, the game's interaction design focuses more on creating and maintaining social spaces than traditional game features.
- Procedural spaces: Procedural space generation offers the potential for players to create their own game worlds, but current examples such as MojoWorld and virtual cityscapes lack interactivity and objects to interact with. Only a few games have used procedural space generation, such as Rescue on Fractalus and Vib-Ribbon, but they have presentation and player control limitations. Vib-Ribbon allows players to generate game levels through music but lacks direct control over the outcome (2006).

2.2 Game Mechanics & Toolset in Digital Games

"Game mechanics are the core of what a game truly is. They are the interactions and relationships that remain when all of the aesthetics, technology, and story are stripped away" (Schell, 2008).

Schell (2008) continues: The complexity of game mechanics makes it difficult to create a universally agreed-upon taxonomy. Attempts to simplify them to a perfect mathematical understanding are incomplete, as demonstrated by economic "game theory", which can only handle simple systems and is rarely useful for designing real games (p. 130). Game mechanics profoundly affect spatial compositions generated in an application's gameplay or virtual environment. How the environment is designed, manipulated, and structured can greatly affect player experiences, behaviors, and actions. This is a two-fold phenomenon:

A. Static space: The properties of space designed by game developers affect how the game is played. For example, games with mechanics that require fast movement or dodging may feature more open spaces or scattered obstacles.

B. Recursive space: Actions made by players may continuously rearrange the virtual environment itself. In turn, this continuous re-compositing shapes the next action going to be made by the player. Wood (2012) explains this with an example: “In ‘Plants vs. Zombies’, gamers cause reconfigurations by inputs that deploy whichever plant they choose to destroy the zombies. As the zombies disappear, the remaining objects reconfigure, and a different space is generated.” This subject will be discussed later in detail.

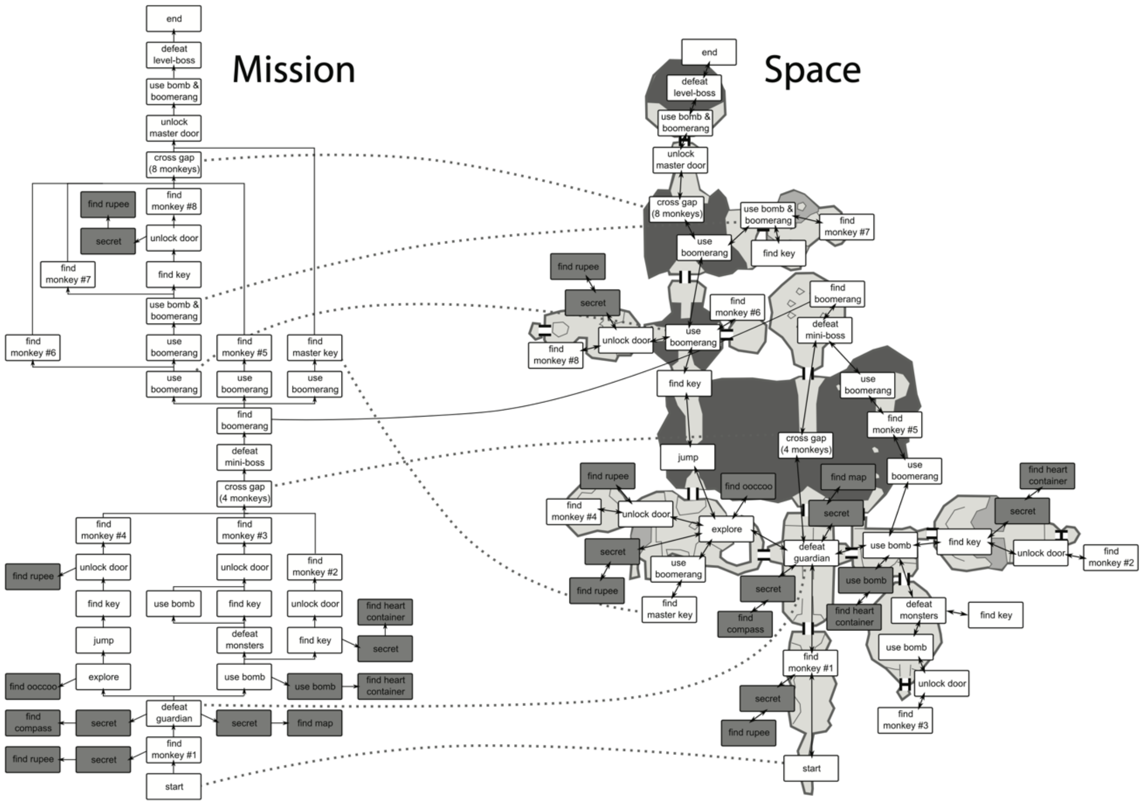

Figure 2.1 : Mission and space in the Forest Temple Level of The Legend of Zelda: The Twilight Princess (Bakkes & Dormans, 2010).

There are several ways game mechanics affect spatial composition and vice versa in a virtual environment. Below, these prospects are laid and matched with the above-mentioned approaches:

1. Navigation: Game mechanics that involve moving a character or navigating through an environment can directly influence the design of the space. For instance, if a game involves climbing or jumping, vertical elements would be significant in the environment (Mostly refers to property A).

2. Progression: Many games use spatial design to signify progress. For example, in role-playing games (RPGs), a player might start in a simple, small town and gradually move to larger, more complex cities as they progress. This kind of environmental progression can shape player expectations and experiences. (Mostly refers to property A).

3. Environmental Interaction: Game mechanics can also determine how players interact with their environment. If players can destroy or build elements of the environment (like in Minecraft), this allows for player-driven changes in spatial composition. If the game mechanics include picking up and using objects, the placement and availability of these objects will significantly affect the environment (Mostly refers to property B).

4. Strategy and Tactics: In strategy games or games with tactical elements, the spatial composition of the environment can greatly impact how a player approaches the game. The positioning of objects, the map's layout, and the terrain types all influence player decisions (Mostly refers to property A).

5. Puzzles and Challenges: Some games use their environments to create puzzles or challenges for players to overcome. The design of these spaces can range from simple, like a series of platforms in a platformer game, to complex, like a labyrinth filled with traps (Mostly refers to property A).

6. Storytelling and Atmosphere: The environment can also help tell the game's story or establish its atmosphere. The layout of a space, its decoration, and

even its size and shape can evoke feelings and suggest certain narratives. This includes everything from the eerie corridors in horror games to the vast, open landscapes in exploration games (Mostly refers to property A).

7. Multiplayer Dynamics: In multiplayer games, the spatial composition of the game environment can influence social dynamics. For instance, spaces may be designed to encourage or discourage player interaction, competition, or cooperation (Mostly refers to property A).

These factors show how closely game mechanics and spatial composition are intertwined. A change in one often necessitates a change in the other, resulting in an ongoing process of adjustment and fine-tuning as the game is developed and played.

In the scope of this research, we will focus on the combination of “recursive spaces (B)” and “environmental interaction (3)” discussed above. But, before we finalize our investigation on the interaction between game spaces and mechanics, we should delve deeper into the third point about “environmental interaction (3)” and how game mechanics can shape the spatial compositions of the game environment. In this case, “environmental interaction (3)” is further dissected into 5 attributes labeled from I to V and presented below:

I. Destructible Environments: In games with destructible environments, players can directly impact the spatial compositions of the game world. Games such as "Red Faction: Guerrilla," "Minecraft," and "Fortnite" allow players to break down and eliminate parts of the world. This mechanic fundamentally changes how players interact with the environment, opening up new pathways, eliminating cover in combat situations, or even using destruction as a way to achieve objectives. It turns the environment from a static background into a dynamic tool that can be manipulated to the player's advantage.

II. Constructible Environments: Some games feature construction mechanics that allow players to create structures or modify the environment. This is most clearly seen in sandbox games like "Minecraft" or "Terraria," where players can build houses, towers, or any structure they can imagine, directly influencing the spatial composition of the world. In a multiplayer setting, these mechanics can foster creativity, collaboration, and competition.

III. Object Interaction: Games that allow players to interact with objects in the environment can also significantly impact spatial composition. This can range from simple interactions, like moving a box to reach a high platform, to more complex mechanics, like in "Half-Life 2," where the Gravity Gun lets players use almost any object as a tool or weapon. This sort of mechanic not only changes the spatial composition but also recontextualizes the objects within the space, turning ordinary objects into potential tools.

IV. Environmental Hazards and Advantages: Some games use the environment itself as a mechanic. Environmental hazards like lava, quicksand, or cliffs can pose challenges for players, while environmental advantages like high ground or cover can provide strategic advantages. In these cases, understanding and manipulating the spatial composition becomes a key part of gameplay.

V. Environmental Puzzles: In some games, environmental interaction can take the form of puzzles. Players might have to move blocks around to clear a path, manipulate light beams to unlock a door or alter the environment in other ways to progress. These mechanics require the player to understand and manipulate the spatial composition of the environment to solve puzzles.

In all these ways, game mechanics can allow for a two-way interaction between the player and the game environment. Instead of the environment acting as a backdrop, these mechanics make it an active part of the gameplay, which the player can manipulate and change. Table 2.1 presented below shows that various popular games were analyzed for their basic attributes and previously mentioned properties (A/B, 1-7, I-V).

Table 2.1 : A set of games analyzed with previously discussed classifications.

Game		Cities Skylines	Fortnite	Minecraft	No Man's Sky	Polybridge 2	Portal	Project Hospital	Simcity 4	Split	Superliminal	Terreria	Tetris	Valheim	Volfied	Snaris
Genre		City building simulation	FPS	Sandbox	Action-adventure survival	Simulation-puzzle	First person puzzle	Business simulation	City building simulation	First person puzzle	First person puzzle	Sandbox	Puzzle	Survival-sandbox	Arcade - puzzle	Puzzle
2D / 3D		3D	3D	3D	3D	2D	3D	Isometric	Isometric	3D	3D	2D	2D	3D	2D	3D
Core game loop		City building Management	Shooting Building	Building Carving	Exploration Action Building	Building Simulation	Puzzle Solving Exploration Mindf**k	Management Building	City building Management	Creating copies of self Manipulate time Mindf**ck	Puzzle Solving Exploration Mindf**k	Building Carving	Control falling blocks	Exploration Action Building	Carve out space without encountering enemy	Control falling blocks Create closed spaces
Game Space	"Static (A)" "Recursive (B)" "Hybrid (A-B)"	B	A-B	B	A-B	B	A-B	B	B	A-B	B	B	B	A-B	A-B	B
	Two most prominent effects of game mechanics regarding virtual space of the game (1 - 7)	3, 2	1, 3	3, 2, (7)	3, 7	5, 3	5, 1	2, 3	3, 2	1, 5	3, 5	3, 2, (7)	2, 3	2, 3	5, 3	3, 2
	If the row above includes “environmental interaction (3)”; What other mechanics are in effect for generating space? (I-V)	II	I, II, III, IV	I, III, IV	II, III, IV	II, III, IV	-	II	II	-	III, V	I, III, IV	I, II, III	II	II, IV	II, III
Game Mechanics	Main mechanic for space generation	City zoning Road building	Construction Navigation Destruction	Construction Destruction Navigation	Exploration Base building	Construction Problem solving	Environment interaction Problem solving	Layout and functional building	City zoning Road building	Create copies of yourself Manipulate time	Forced perspective Optical illusion	Construction Destruction Navigation	Move incoming shapes	Crafting	Claim playfield	Move incoming shapes Create closed spaces
	How significant is the spatial generation mechanic in overall gameplay? 1:inconsequential	4	2	5	4	5	5	2	4	5	5	5	5	2	5	5

2.3 The Player's Lens

This part will focus on the user's agency in interacting with virtual space in digital games. But before doing that, we must step back and understand the main interaction between the player/user and the game/software. Interaction between user and computer and/or hardware (interfaces, devices, haptic feedback, etc.) is not in the scope of this research, so they are deliberately omitted.

2.3.1 The player's agency in generating space

The player interacts with the virtual environment by playing and actively deciding to depend on the input from the state of the game. So, any input from the player creates a change of state in a virtual environment, and this modification becomes the following input for the player to decide on. The sum of all decisions made during the play session creates a whole, a composition, or in other words: a "recursive space".

According to Wood, the generation of space during gameplay emphasizes that it is not simply a representation of physical space within the game's frame. Instead, it involves rearranging the relationships between objects on the screen. These configurations are called "space" since they determine what is visible on the screen. Both gamers and the game itself contribute to reconfiguring this space, with the game referring to the programming and hardware of the game technology. The outcome of gameplay results from the combined agencies of both gamers and the game. This space is recursive, which is influenced by feedback between the game's state (object relationships) and the gamer's state (knowledge, skill, mood, attention). The concept of "recursive space" serves two purposes: describing a gamer's engagement with space, highlighting the involvement of technology, and conceptualizing play as a process of space creation (2012).

Nitsche confirms and expands the idea of the synergy of player and virtual environment: The intricacy of interacting with the spatial environment of a game involves a dynamic process of transitioning between various spatial arrangements. By examining how a gamer actively participates in creating and exploring these configurations, we can enhance our comprehension of engagement (2008).

‘‘The constant renegotiation of the player’s position is key, and the multi-layered quality of the game space opens it up for dynamic engagement (Nitsche, 2008, p. 181).’’

This phenomenon is not limited to virtual environments as well. We can find similar processes in real-life situations, especially during design processes.

In the architectural design process, we make thousands of small decisions that relate to and bind each other. All these consecutive small decisions add up to represent a whole building in great detail. For example, A decision on structural axes -usually done early in the design process- will affect most other spatial decisions later.

A similar process of generating a recursive virtual environment also occurs in the game Simcity. We start with an empty area to develop a city. Most players first do “zoning” and establish the city’s main arteries. These fundamental decisions later create substantial problems in managing the city if done poorly.

2.3.2 Co-creation of game worlds: multiplayer

In multiplayer virtual environments, game mechanics also impact social interactions and the generation of shared spaces. Mechanics such as cooperative puzzles, competitive challenges, or team-based objectives can foster collaboration and competition among players, creating shared spaces where players interact, cooperate, or compete with each other. These mechanics can enhance the social dimension of virtual space and promote a sense of community among players.

Schell argues, "Clearly, playing with other people is natural, and in fact, the preferred way for us to play games” (2008). Schell continues to elaborate on the main reasons why we play games with other people:

- “Competition” is typically the foremost aspect that comes to mind when considering multiplayer games. This enables a fair and equitable game on an even battleground, gives us a challenging rival, satisfies the inherent desire to assess our abilities compared to others within our social group, and enables the inclusion of intricate strategies, decision-making, and psychological elements in games, made possible by the intelligence and expertise of our human adversary.

- "Collaboration" enables us to engage in in-game actions and utilize strategies that would be unattainable with only a single individual and allow us to experience the inherent and possibly evolved profound joys derived from collaborative problem-solving and being a valued member of a victorious team.
- "Meeting Up"*:* Games provide a convenient and comfortable way for friends to gather, offering a shared activity and a focal point for interaction, easing social awkwardness, and avoiding discomfort.
- "Exploring our Friends": Games offer a unique opportunity to delve deeper into the minds and personalities of our friends beyond mere conversation. Unlike in conversations where responses may be filtered, games reveal unvarnished truths as we witness their problem-solving abilities, decision-making under pressure, and their tendencies to cooperate or betray. This experience allows us to learn about their trustworthiness and true nature.
- "Exploring Ourselves": Games played alone help us explore personal abilities and preferences. When played with others, they reveal our behavior in complex social situations, our coping mechanisms, and our interpersonal dynamics (2008).

Acharya & Wardrip-Fruin assert that co-creative games feature the shaping of game worlds at their core, allowing players to participate in the creation process actively. This involvement is explored through examples and analysis of the game features that enable co-creation. Understanding the key elements of game world co-creation helps us recognize it in existing games and design future games that support this collaborative process. By giving players the role of makers, they can modify the game world for themselves and others, blurring the lines between game authorship and play. This approach fosters collaborative worldbuilding among players, leading to new player-driven stories and worlds where players become vital creators. Identifying this "co-creative process" provides a fresh perspective on collaborative storytelling in games, highlighting how players shape narratives through the shared manipulation of game worlds and assume authorship roles through play (2019). Combining the mentioned "co-creative process" with the idea of "recursive space", we can argue that collaborating to create and re-iterate virtual environments is one of the key aspects of playing with others.

3. METHODOLOGY

To research the player's agency in generating virtual space, we must first address how we can measure the player's involvement in space generation and manipulation in games. To test this, the author envisioned an application in which we can isolate the existence of game mechanics. By switching the game mechanics on and off, we can effectively evaluate the effects of rulesets on space creation.

This chapter explores the methodology utilized in this study, focusing on the influence of game mechanics on the development and alteration of virtual environments. Our primary approach involves a two-state application called Snaris, which consists of the Play Mode incorporating game mechanics and the Build Mode lacking such limitations, enabling unrestricted construction. Playtests done with this application are our main data-collection method. Lastly, the evaluation framework of data gathered from the playtests will be discussed. But first, we will investigate the design and development of Snaris before we elaborate on the evaluation and test methodology criteria used in this research.

3.1 Design and Development of Snaris

In this section, we will investigate the core elements and functions of the application: its generative capacity, limitations, game mechanics, and influences. The space generation procedures are going to be the focal point of this chapter. Finally, we will retrospectively look at the design and development process of the application.

3.1.1 Overview

At its essence, the player directs a continuous flow of blocks within a 3D space, creating diverse structures, shapes, and spaces. The virtual environment, scene, or level dynamically develops and emerges from the player's intentional or accidental actions. The player is in control of the constant movement of blocks within a 3D space, resulting in the creation of game space. Therefore, the player continuously negotiates their spatial decisions.

The space generated in Snaris is recursive, meaning that the outcome of gameplay emerges from the combined agencies of both gamers and the game's ruleset.

The application features two primary modes that allow the researcher to observe the impact of risk and reward mechanics on generating spatial relationships. The first mode is Play Mode, in which the game mechanics govern the session and the objectives. In the second mode, Build Mode, gameplay, user interaction, and control scheme remain the same, except for the absence of rulesets.

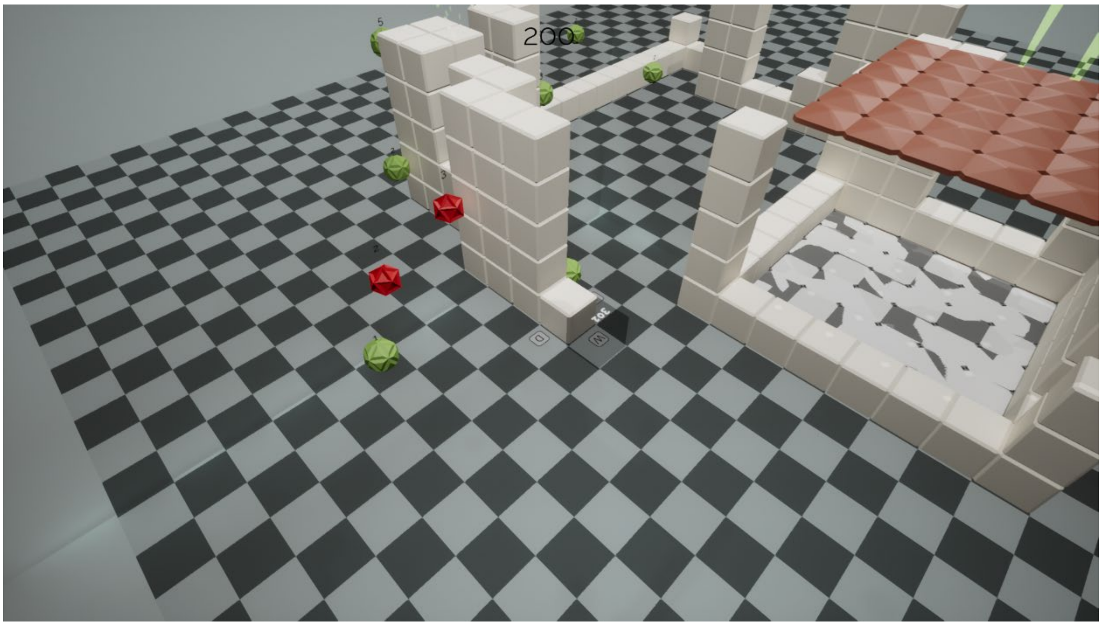

Figure 3.1 : Gameplay screenshot in perspective view (Play Mode).

The application falls under the genre of a single-player 3D puzzle game. It emphasizes developing and utilizing various skills such as gaming skills, 3D spatial perception, intuition, real-time decision-making, and comprehension of complex spaces. Additionally, the application offers alternative uses beyond gaming, serving as a 3D sketching and modeling tool, facilitating education on spatial relationships, and incorporating gamification into architectural education. At this stage, it is designed for use on the PC platform, but the game appears to be more idiosyncratic for the mobile platform. Thus, in the future, the application might be updated and re-developed for mobile devices.

3.1.2 Motivation

Various games influenced Snaris and its mechanics. There are 4 main reference games that helped the author design various application properties: Tetris, Snake, Volfied, and Minecraft. Plus, there is an earlier work created by the author called 3dTetris. We will discuss which game influenced which mechanical property of Snaris later in this chapter. The main influences for core mechanics are shown below, and in parenthesis, the mode of Snaris that the game influenced is indicated.

- Tetris: Moving blocks, gaining points by creating certain spatial situations.
- Volfied: Space enclosure mechanic.
- Snake: Directing the flow of blocks, risk, and reward mechanics (Play Mode).
- Minecraft: Sandbox-like creativity and spatial experimentation (Build Mode).

Tetris, first released in 1984, is a puzzle game where the player must arrange falling blocks (tetrominoes) in a way that they create complete lines across the game grid. Each tetromino comes in different shapes and can be rotated as it falls. When a complete line is formed, it disappears, freeing up space. If any block reaches the top of the screen, the game ends. The goal is to score as many points as possible, which is done by clearing multiple lines at once.

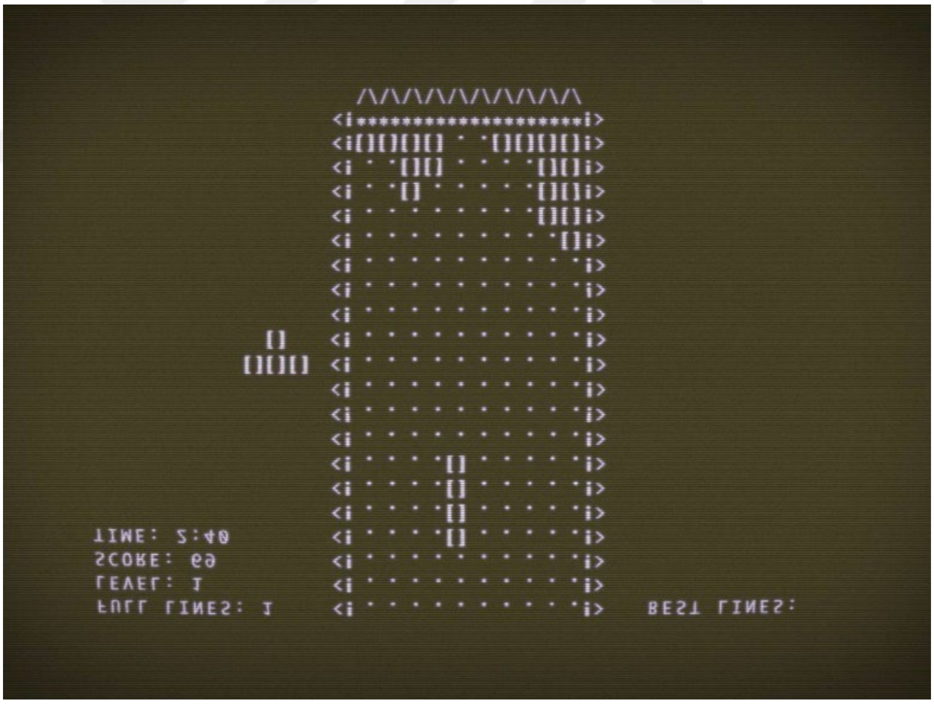

Figure 3.2 : Tetris was originally developed for the “Electronika 60”, a Soviet computer.

In Tetris, the risk-reward system is inherent in the gameplay itself. The reward is clearing multiple lines at once, especially achieving a "Tetris" (clearing four lines at once), which gives more points than clearing individual lines. The game also speeds up as the player progresses, increasing the risk as well as the potential for higher scores.

In Volfied (1989), the player controls a spaceship-like object, and the goal is to claim at least 80% of the playfield while avoiding contacting enemies. The player can draw lines to cut off parts of the playfield. When the player's line encloses an area, that area becomes filled or "claimed." However, if an enemy touches the player's line before it becomes a completed box, the player loses a life. Additionally, there are power-ups and bonuses that can aid the player.

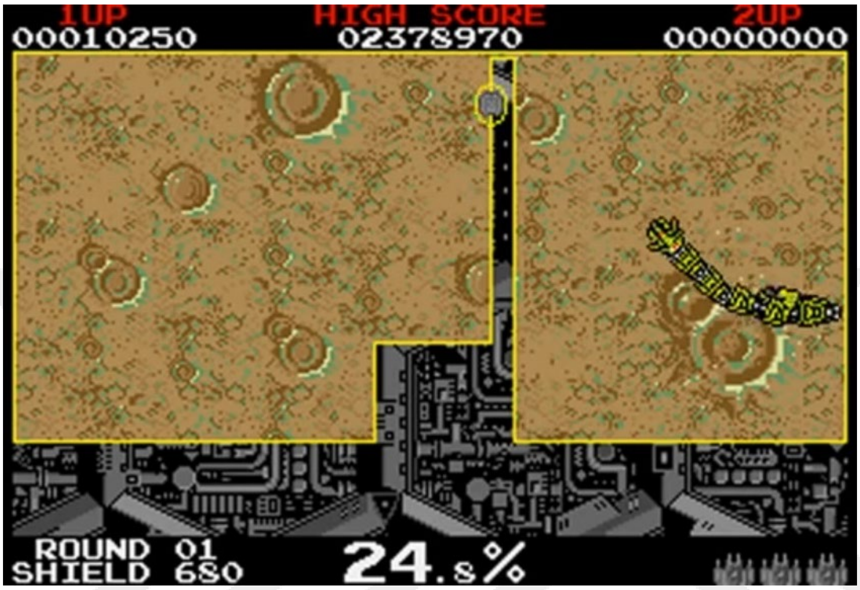

Figure 3.3 : Volfied (1989) was developed by Taito and was initially released for arcade computers.

In Snake, the player controls a line or "snake" that grows longer each time it eats food appearing randomly around the play area. The goal is to eat as much food as possible without the snake running into its own tail or the walls of the play area. The game gets progressively harder as the snake grows longer and ends when the snake hits itself or the wall.

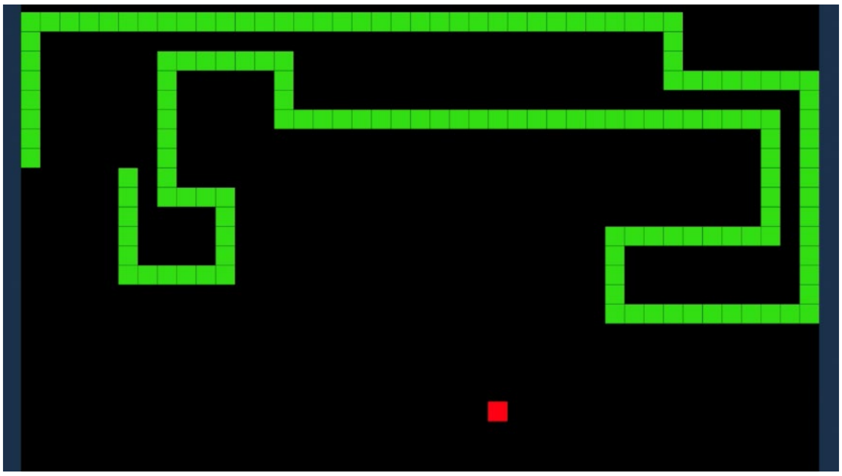

Figure 3.4 : Snake originated in 1976 from the two-player arcade game Blockade.

The primary risk-reward mechanism in Snake is the constant increase in the snake's length as it eats food. Each piece of food eaten (the reward) also increases the difficulty of the game (the risk) because the snake becomes longer and, thus, more likely to run into itself, which ends the game.

Minecraft is a sandbox game with two main modes: Survival and Creative. In Survival Mode, players must collect resources, build structures, battle monsters, manage hunger, and explore the world in order to survive and thrive. In Creative Mode, players have unlimited resources, can fly, and are invincible, focusing on building and creating. The game is also notable for its crafting system, which allows players to combine collected items in specific ways to make tools, items, and building materials. Players can also engage with villagers, animals, and various types of enemies. Minecraft also offers a multiplayer mode where players can collaborate or compete with others in the same game world.

Figure 3.5 : Minecraft (2011).

In Minecraft, there are multiple examples of risk-reward mechanisms. One prominent example is mining, where players dig deep into the ground for valuable resources, risking encounters with hostile creatures and other hazards. Another example is the Nether and The End dimensions, where players can find valuable resources and fight challenging enemies, but these dimensions also present significant dangers. The game's Survival Mode is all about balancing risks (monsters, hunger, environmental hazards) with rewards (resources, advancement, exploration).

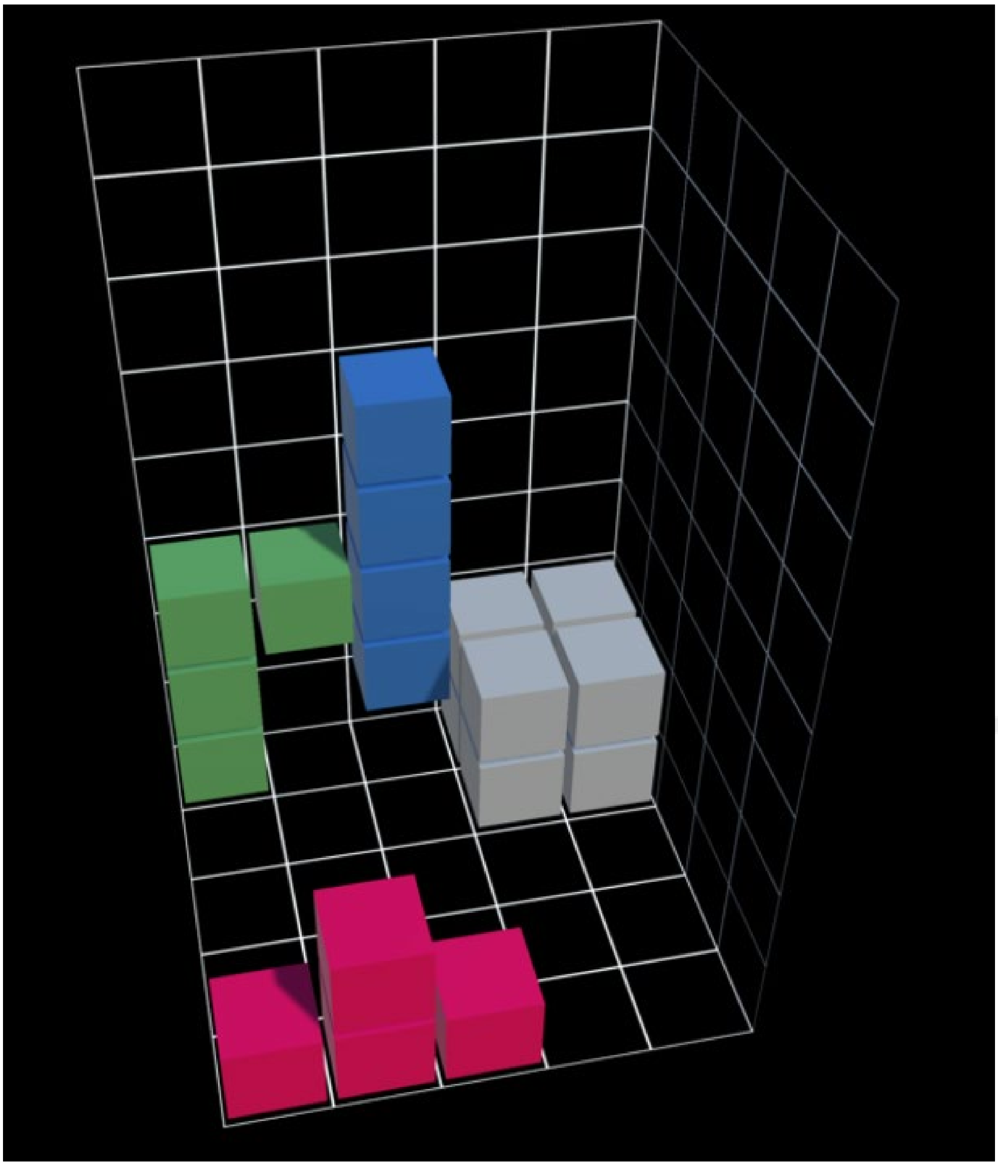

Figure 3.6 : Gameplay image from 3dTetris, a preliminary study by the author (2022).

All four previously discussed games and 3dTetris's features, such as year of release, platform, virtual environment dimension count, influence on design the of Snaris, game progression type, risk and reward system, and simplified game loops, were summarized in Table 3.1 below.

Table 3.1: Tetris, Volfied, Snake, Minecraft, 3dTetris, Snaris.

Name of the game	Year of release	Main platform	Virtual environment	Game progression	Risk / reward system	Loop	Logic	Influenced the development of Snaris
Tetris	1984	Micro computer	2D	Continuous flow	Clearing multiple lines at once / Speeds up as you progress, increasing the risk but also potential for higher scores.	*Check player input (rotate, move, or speed up falling block) *Update block position (blocks fall over time) *Check for complete lines and remove them *If the game board is filled to the top (losing condition), end the game *Spawn a new block *Repeat	Each filled up row gets deleted to make room for limited game space to increase play time, thus gaining more score	Play mode
Volfied	1989	Arcade	2D	Discrete actions	Completing a level by claiming at least 80% of the screen, power-ups / Exposing the avatar to greater risks and tougher enemies	*Check player input (move ship, draw line) *Update player and enemy positions *Check if a line is completed and fill in enclosed area *If enemies touch player's incomplete line or the player's ship, decrement life count *If the player has claimed 80% or more of the screen, advance to the next level *If all lives are lost, end the game *Repeat	Players control a spaceship to claim territory on a grid. They must create boundaries while avoiding the enemy. Players aim for the highest score before running out of lives or time by progressing through levels and claiming as much territory as possible.	Play mode
Snake	1976	Arcade	2D	Continuous flow	Each piece of food eaten (the reward) also increases the difficulty of the game (the risk) because the snake becomes longer and thus more likely to run into itself, which ends the game.	*Check player input (change snake's direction) *Update snake position *If the snake eats food, increase its length *If the snake collides with itself or the game area boundaries, end the game *Spawn new food *Repeat	Players control a snake that moves around a grid. The goal is to eat food and grow while avoiding walls and your own body. Players control the snake's direction, and it moves continuously. If you collide with a wall or yourself, the game ends. Each time the player eats food, they get points. The game gets harder as the snake grows longer.	Play mode
Minecraft	2011	PC	3D	Discrete actions	The game's survival mode is all about balancing risks (monsters, hunger, environmental hazards) with rewards (resources, advancement, exploration).	*Process player input (movement, building, combat, etc.) *Update world state (block changes, enemy movements, day/night cycle, etc.) *Check if the player has died (in Survival mode) or if any other game-ending conditions have been met *Render the updated world *Repeat	Players explore a blocky world, gather resources, and build structures. Survive by finding food and fending off enemies. Play solo or multiplayer, unleashing creativity in a limitless sandbox environment.	Build mode
3dTetris	2022 (prototype)	PC	3D	Continuous flow	Same as Tetris, but in 3d. This creates navigational challenges.	Same as Tetris, but in a 3D container, rather than a 2D rectangle shaped border	Same as Tetris.	Build mode
Snaris	2023 (prototype)	PC	3D	Continuous flow	Higher points in the play mode are often achieved by creating large rooms, but the buggy algorithm may not register the enclosure, thus not logging game points.	*Decide Z plane movement *Decide wall height *Decide elevation *Repeat	Build mode: Build structures with available mechanics. Play mode: Get the highest point by enclosing game point objects while avoiding colliding with previously laid blocks.	-

3.1.3 Game mechanics and principles for space generation

The primary activity for the player is creating virtual spaces by placing blocks in a 3D scene. This involves directing and controlling the position of blocks that continuously emerge and move (translate). The blocks originate from the center of the screen and appear at a predetermined rate set at the beginning of the game. Additionally, the player has control over the height of the walls by instructing the game to finalize the current wall and proceed to the next line.

The application focuses on enclosing spaces (rooms) to accumulate points within them. Achieving this involves the game's detection of a closed space when viewed from above, which triggers the automatic filling of new blocks on the top (reddish roof elements) and bottom floors.

In the Play Mode, the game features a point system where players earn positive points (indicated by green) and negative points (indicated by red) by enclosing the objects in a room. The points objects disappear from the game session if any block contacts with them. The game is over if blocks overlap or if any blocks extend beyond the boundaries of the playfield. On the other hand, in the Build Mode, the game ends solely when blocks exceed the boundaries of the playfield.

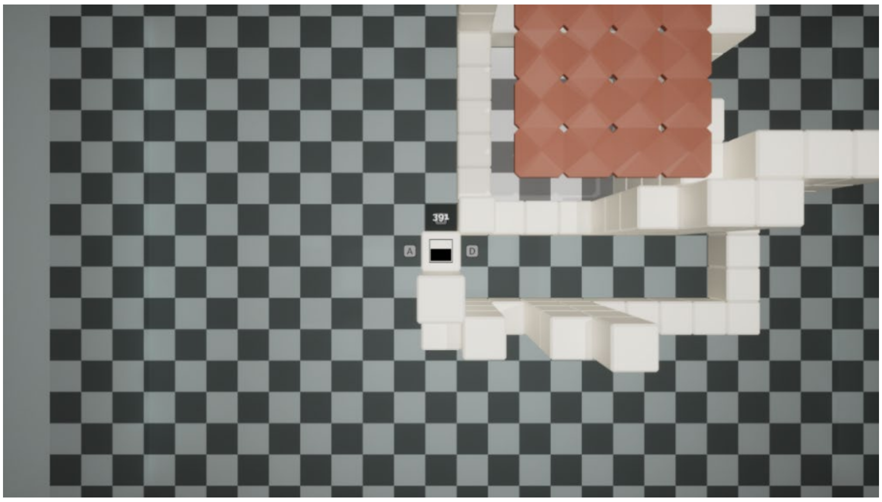

Figure 3.7 : Gameplay screenshot in top view of Snaris (Build Mode).

In Build Mode, the mechanics of rewards and risks are concealed, allowing players to start with a blank canvas of a 3D world to construct and experiment with -within the confines of the spatial generation abilities of Snaris-. The game's initial setup properties, the player's gaming skills, ambition, and creativity determine the outcome of this mode. The input scheme (game controls) remains consistent with the Play Mode, providing a controlled testing environment to examine game mechanics.

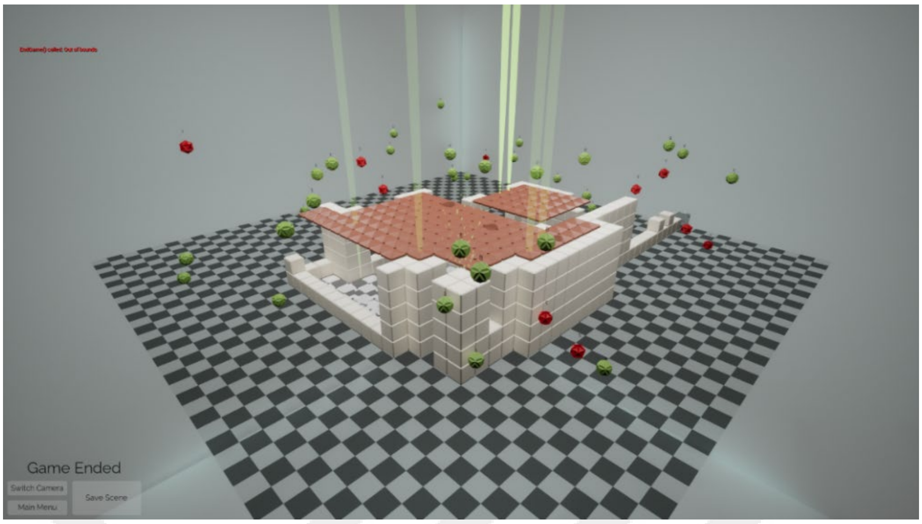

Figure 3.8 : End-game screenshot from Snaris (Play Mode).

For the room enclosure mechanic to work, we used the “flood fill” algorithm to detect if the walls create any confinement in the top view. Smith explains the algorithm as such: Flood fill, or seed fill, is an algorithm that floods an area connected to a specified node in a multi-dimensional array, modifying it based on a matching attribute. This algorithm is commonly employed in paint programs' "bucket" fill tool to fill connected areas of the same color with a different color. It is also utilized in games like Go and Minesweeper to identify cleared pieces (1979, pp.276-283). In Snaris, the space is automatically “closed” if all the boundary walls have at least one block.

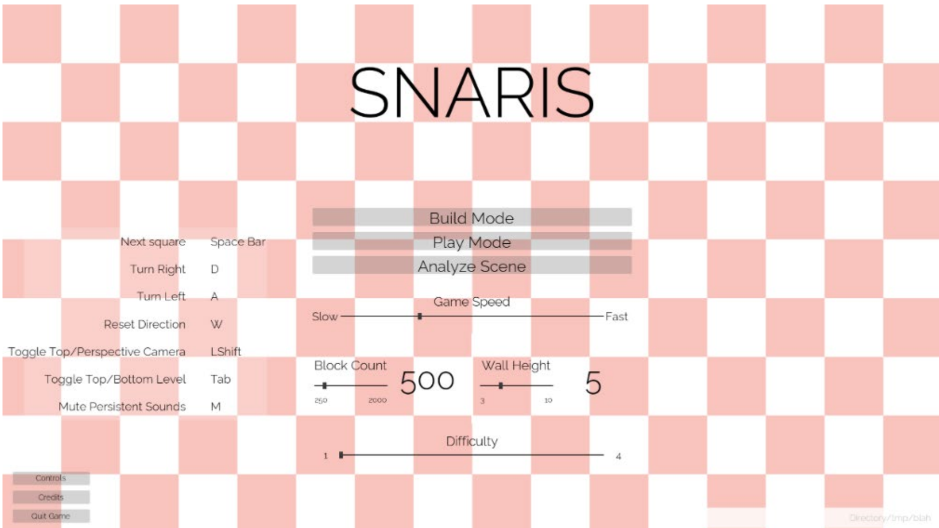

Figure 3.9 : Main menu/game setup page of the application.

3.1.4 Design and development process

In the first phase of design, on-paper sketches and several iterations of animations were created in Blender. These animations helped the author to understand the gameplay better, revise ideas, and communicate the design with other people. After some iterations, the game design document (GDD) was created. Later, with the guidance of GDD and multiple meetings with the author, Ali Ersoy developed the application in Unreal Engine 5. The author was supervising the development process.

At this stage, we aimed to create a proof of concept or prototype of the application. This means the application is completed to the stage that is polished just enough to organize playtests related to this research. The main objective during this stage was to create an alpha version of the application that includes all the essential mechanics. Thus, the quality of audio, visual effects, assets, overall aesthetics, or extended game mechanics was a second priority. However, as a game concept, it is thought that we can later strive for a release version too.

Some originally thought features could not be implemented due to technical, skill-wise, and time-wise limitations of both the author and the developer. These will be laid out later in this chapter.

The current version of Snaris serves as a study bench for investigating the effects of game mechanics on generating virtual environments while employing a game-like user interface. Since virtual environments can be vastly diverse in terms of form, topology, complexity, texture, lighting, etc., only certain simple spatial configurations can be achieved in this application with its current space generation procedure. Some of the limitations regarding the space generation abilities of the application are presented below:

- Only orthogonal and *voxel*-based structures can be achieved.
- Slated walls are impossible to create.
- Organic shapes and structures cannot be created.
- Wall height is determined during setup; thus, exceeding a certain height in a game session is impossible.
- The design of the application only allows two levels.

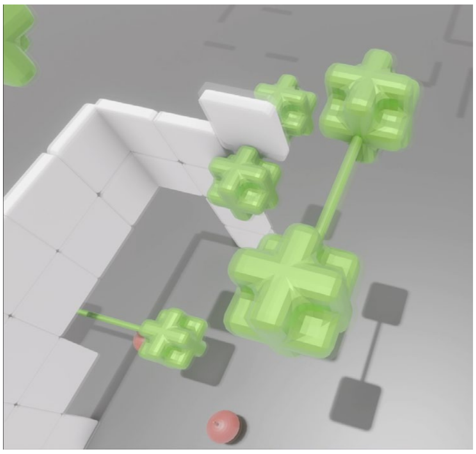

Figure 3.10 : Prototype of the game created and animated in Blender. The connections between green objects are later discarded in the development process.

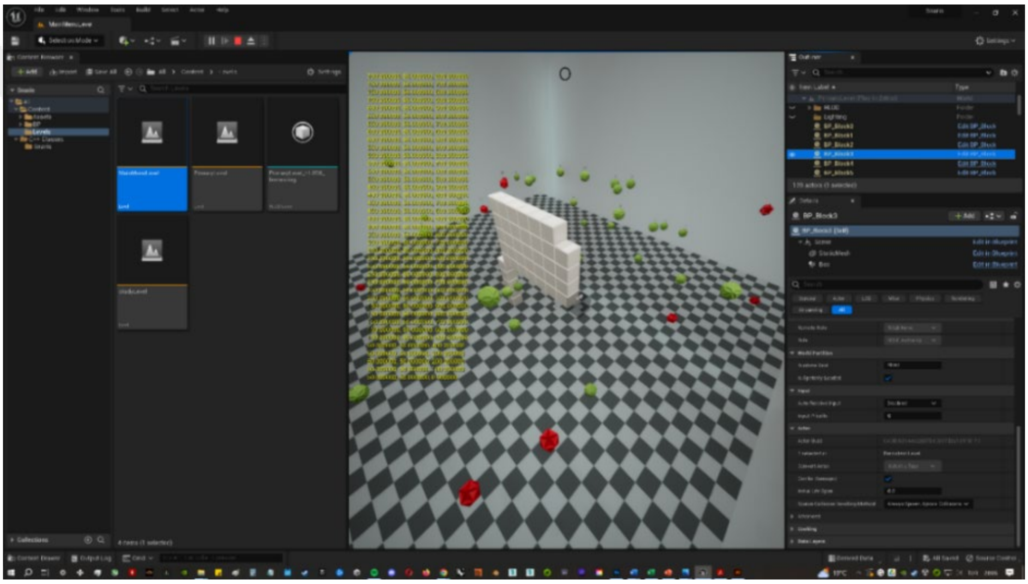

Figure 3.11 : Application development in Unreal Engine 5.

Features that could not be achieved during the development:

- In the original idea, the highest wall block determined the roof elevation for that closed space, in the current state of the application, the roof is created on a fixed elevation that is established in the game setup.
- In the current stage of the application, blocks only spawn and fill the walls from below toward above. Originally it was intended for block spawn direction to be toggled in two ways: from above to below and the other way around.
- The room closure mechanic is somewhat buggy and does not always work as intended. However, this feature gave the idea to differentiate closed spaces with roofs and without roofs when analyzing spatial compositions.

Table 3.2: Excerpt from the "game design document" explaining essential and optional goals to achieve for the prototype stage of development.

Core mechanics have to be implemented for the testing stage
*Both Game mode (2-3 pre-designed levels) and Builder Mode *Scaling of blocks relative to their orientation. (refer to video) *Directing the flow of blocks relative to top view. *Next line command: End current line/wall of blocks and jump to next. (refer to video) *Ability to move to upper or lower floors (refer to video) *Horizontal slabs of blocks that automatically detects and closes the room. *A game point counter system *Game speed configurator *Configurable wall height : Number of max. blocks in every floor. (4 in animation video) *Block count: For Game mode, this is needed for ending the game and to evaluate the session. For Builder mode, this is needed for the app to not to last for eternity. *Rewards (countable game points) *Camera system that follows action. (currently WIP, to be decided later) *Most basic UI that is possible (examples in following pages)
Optional objectives for the testing stage
*Reward connections and breaks up of one of the connected rewards. (Refer to the previous page and video) *Risks (refer to the first page) *Switch for blocks moving from upside-down or opposite (In game selector) *Implementing a FBX, USD or similar 3d file export option of the completed game session. *A system that shows any game object's elevation. This is needed because it is unclear where exactly the rewards and risks are in the 3d view. This is open to further discussion.

3.2 Evaluation Framework

We elaborated on the spatial generation principles and design of the Snaris in the previous chapter. The application is designed in a way to isolate the effects of game mechanics while creating space in a virtual environment. These are Play Mode and Build Mode, as we discussed earlier.

This section focuses on the method for evaluating spatial compositions created in both modes of testing apparatus. The main method for data gathering is playtesting. This method is chosen because this application is designed with two states so that we can easily isolate the effects of game mechanics. Thus, the author decided to carry on with a method that is as close as it gets to a controlled experiment setup. Therefore, playtesting would be this specific study's most idiosyncratic testing method.

Playtesting, a common practice for gathering feedback during game development, is originally intended to ensure a game's quality and evaluate the player's experience. This method helps the designers shed light on whether the game in development is experienced by the user as intended. According to Davis et al., the objective of the playtest is to systematically gather feedback from players regarding their experiences with a particular game, employing scientific approaches. The ultimate aim is to offer game designers practical feedback from players on how they interpret crucial elements of their games (2005). Moreover, Davis et al. also claims, "One of the hallmarks of the playtest is experimental control" (2005).

However, in this research, we use the term playtesting to analyze comparable and quantifiable end-game results to understand and evaluate various scenes rather than a quality assurance step in the game development process. Below, an overview of playtesting, data gathering, and evaluation process, which we can colloquially call the evaluation framework, is presented.

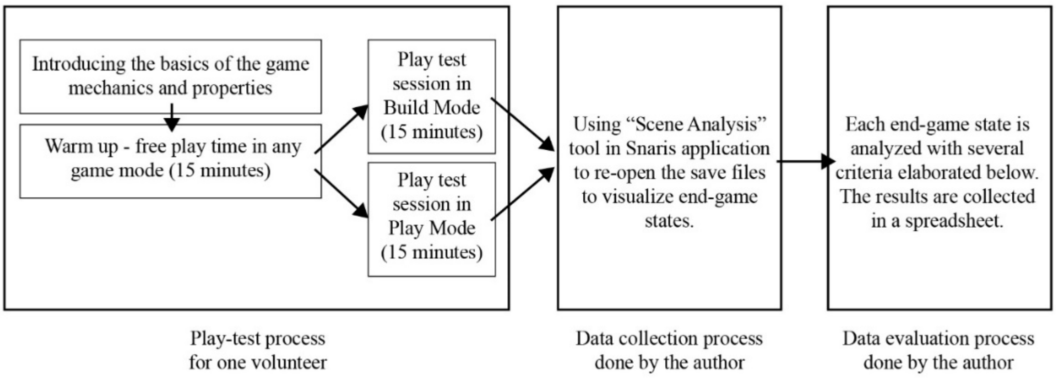

Figure 3.12 : Overview of the evaluation framework.

The author proposed a group of criteria to quantify the properties of spatial compositions created in both modes of Snaris. These criteria will be used to evaluate various aspects of virtual environments generated during the playtests. These specific criteria, among an infinite number of possible ones, are chosen due to the unique nature of the application, its ability, and its limitations while organizing space. Further information on criteria will be presented in chapter 4.2, but a summary is presented below:

- LC: Level count (Figure 3.13).
- DB: Distribution of blocks on various levels (Figure 3.13).
- WV: Height variation in a facade or wall (Figure 3.14).
- RC: Roof element count (Figure 3.14).
- RR: Ratio of roof elements' coverage in the entire composition, in other words, the ratio between closed and open spaces (Figure 3.15).
- AR: Total area of the roof in the composition (Figure 3.15)
- CC: The number of closed spaces without a roof created (Figure 3.16).
- AC: Total area of unroofed closed spaces (Figure 3.16)
- AV: Total area of roofed and unroofed closed spaces (Figure 3.16)
- BB: Bounding box size (Figure 3.17).
- XY: Birds-eye view horizontal and vertical sprawl ratio (Figure 3.17).
- TB: Total number of blocks used in the session (Figure 3.17).

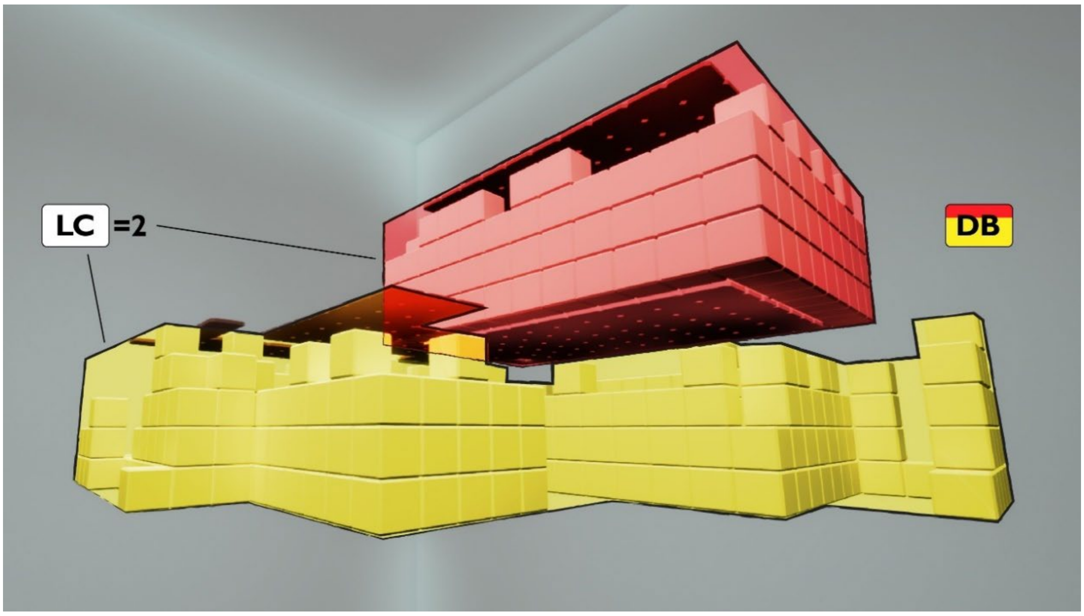

Figure 3.13 : Level count (LC) and Distribution of blocks on various levels (DB).

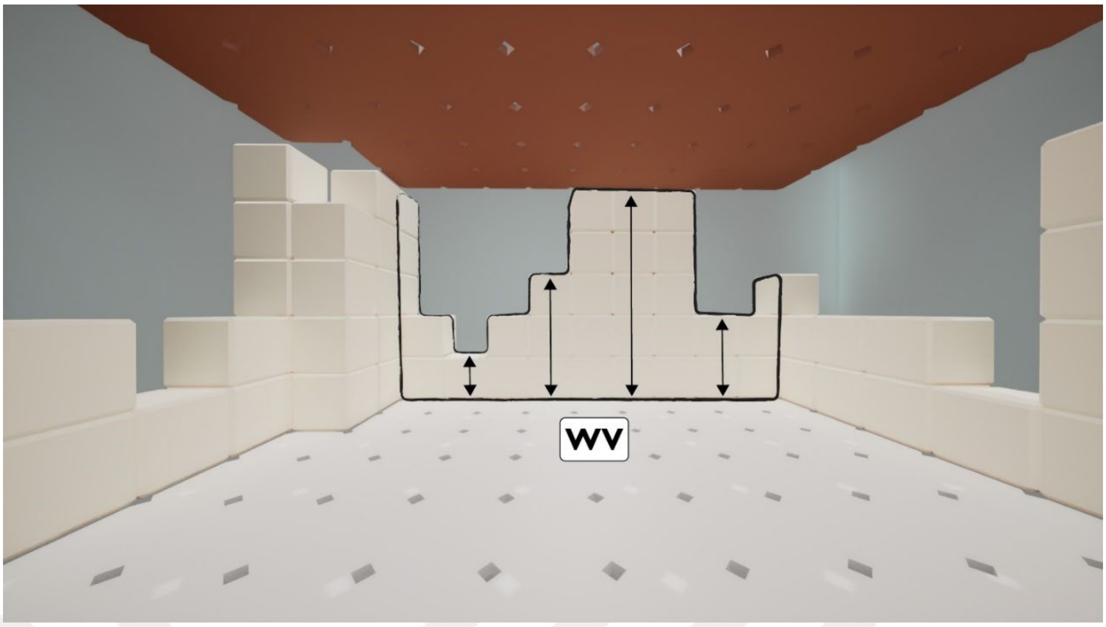

Figure 3.14 : Height variation in a facade or wall (WV).

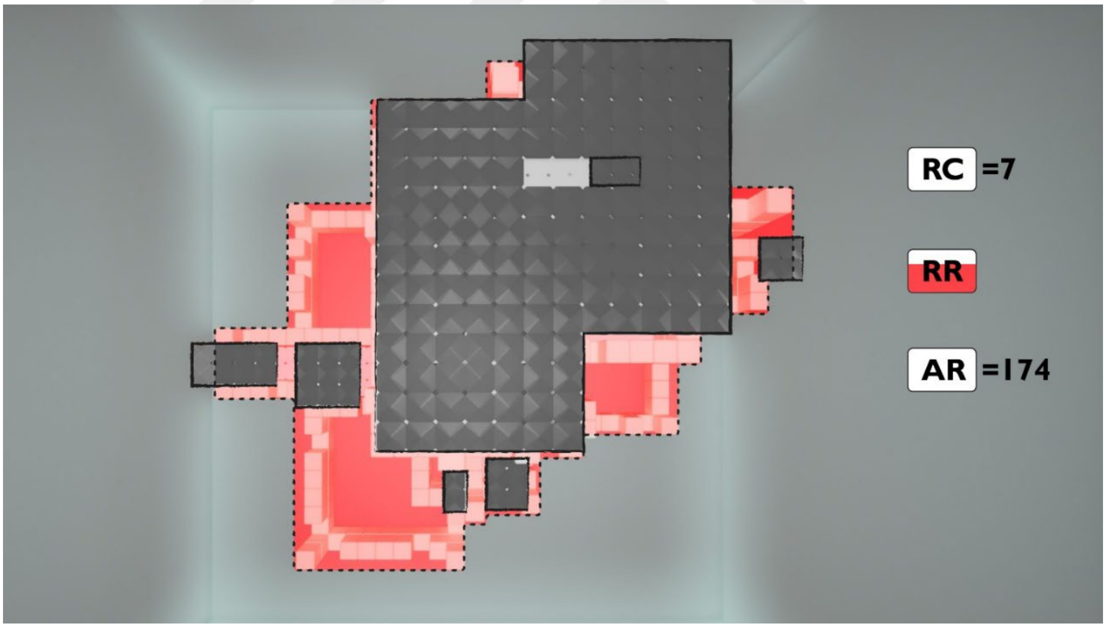

Figure 3.15 : Roof element count (RC), Ratio of roof elements' coverage in entire composition (RR), Total area of the roof in the composition (AR).

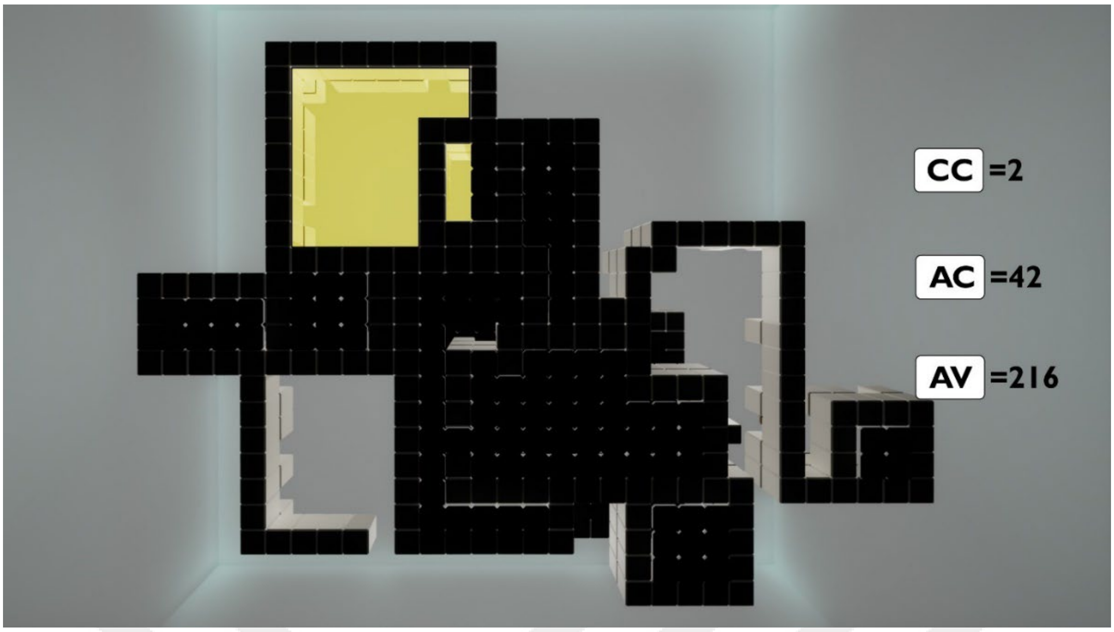

Figure 3.16 : Count of closed spaces without a roof (CC), Total area of unroofed closed spaces (AC), Total area of the roof, and unroofed closed spaces (AV).

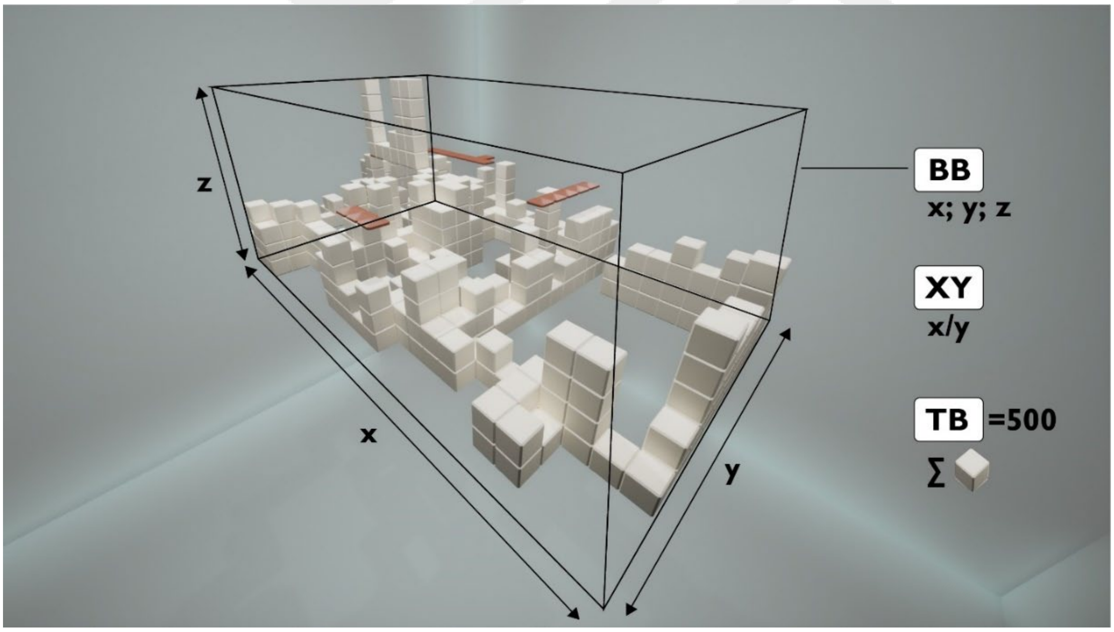

Figure 3.17 : Bounding box size (BB), Birds-eye view horizontal and vertical sprawl ratio (XY), Total block count (TB).

4. CASE STUDY: SNARIS

Rogers (2014) jokingly remarks: “I think it's fair to say most video games let players experience only eight emotions: anger, panic, dread, surprise, wonder, satisfaction, joy, and disappointment. And some games only disappoint” (p. 234).

This case study investigates:

- The impact of particular risk & reward mechanics in Snaris while generating space in virtual environments.
- The player's dual role as the subject and object in creating a virtual environment.
- Compare & contrast spatial compositions created in two distinct modes in Snaris and make deductions.

4.1 Data Collection

Ruddle et al. state that the challenge of finding one's way in unknown physical environments highlights the necessity of providing navigational assistance in virtual environments. Since virtual environments are always new to users upon initial use, it can take several hours to become adequately acquainted with the space and navigate it successfully without assistance. This may be a significant investment of time that users are not necessarily willing to make (1997).

In this research, Snaris serves as a tool to facilitate a controlled experiment apparatus. This application is designed with two modes, one involving an arbitrary set of risk and reward mechanics and another allowing free spatial creation. In addition, a mode to re-open and navigate in a saved end-game scene. Thus, the primary focus of comparison lies between Play Mode and Build Mode, which is elaborated on in Chapter 3.1.

Playtests were conducted with 20 participants. All participants are competent in gaming, although with varying degrees of dedication. This benefits the study since the application requires some coordination and accustomedness in general gaming praxis on PC. Half of the participants are trained architects. The other half is trained in various trades unrelated to design practice.

The playtests were conducted for one participant at a time. In each session, the author briefly introduced the game, its two modes of operation, the control scheme, and the game mechanics. Then, for 15 minutes, the volunteer could freely explore and use the application in any mode they desired. In this stage, participants were encouraged to use all two application modes roughly equally in terms of time spent. Later, the author asked the participant to use the application for 15 minutes continuously in both Play Mode and Build Mode and submit the end-game state from each mode as a save file. This way, a session of playtesting took about an hour.

Later, the author collected submitted save files and re-created each end-game scene using the "analyze scene" mode in Snaris. The scene can be freely navigated through in this mode, just like in a game engine. The author then evaluated each scene with the criteria laid out in Chapter 3.2.

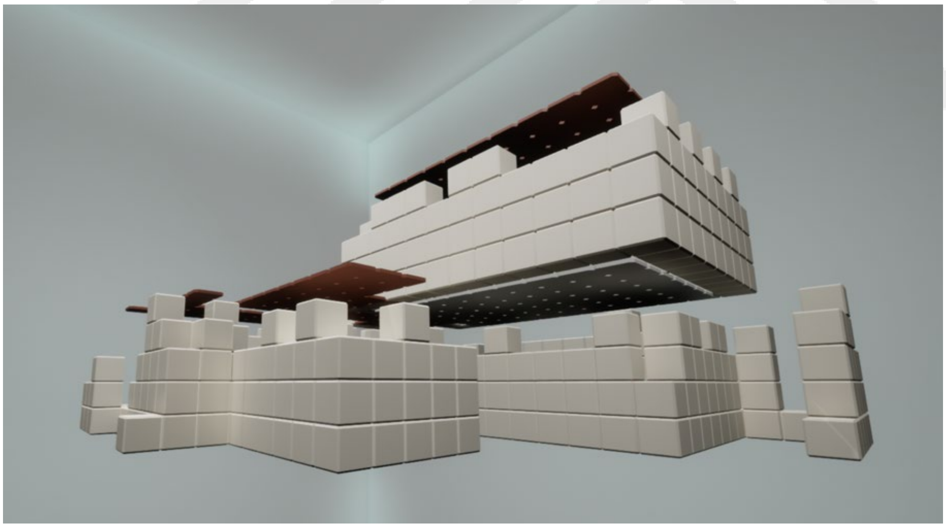

Figure 4.1: View from the "analyze scene" tool in Snaris.

4.2 Analysis and Findings

The data collected from playtests are shown in the table below. At the bottom, three rows of the table are dedicated to the mean average, highest, and lowest values for each data column to help us understand and interpret the information later. The mean average was chosen for calculation rather than the median method. This is due to the data being reasonably consistent among different scenes.

Table 4.1: Playtesting data.

Playtests		Evaluation Criteria																					
Test Session #	Application Mode	Level Count (LC)	Distribution of blocks on levels (DB)		Height variation in the scene (WV)							Roof element count (RC)	Roof coverage ratio (%) (RR)	Total area of roof (AR)	Closed spaces without roof (CC)	Total area of unroofed closed spaces (AC)	Total area of roofed and unroofed closed spaces (AV= AR + AC)	Bounding box size (BB)				Horizontal and vertical sprawl ratio (XY)	Total count of blocks in scene (TB)
			Top level (%)	Bottom level (%)	Number of walls with block heights indicated below						Average wall height in scene							X direction	Y direction	Z direction	Volume (X*Y*Z)		
					1 Block	2 Blocks	3 Blocks	4 Blocks	5 Blocks	5+ Blocks													
Test Session 1	Build (Fig. A.1)	2	30	70	27	9	59	57	10	0	3.09	1	91	192	0	0	192	22	19	9	3762	0.863	500
	Play (Fig. A.2)	2	11	89	2	3	5	15	15	0	3.95	1	8	9	1	74	83	14	14	10	1960	1	272
Test Session 2	Build (Fig. A.3)	2	3	97	2	0	1	0	98	0	4.95	2	3	2	4	31	33	26	7	10	1820	3.714	500
	Play (Fig. A.4)	2	22	78	0	0	0	0	100	0	5	8	17	30	0	0	30	13	21	10	2730	0.619	500
Test Session 3	Build (Fig. A.5)	2	31	69	37	170	34	4	1	0	2.03	8	70	225	1	39	264	31	23	9	6417	1.348	500
	Play (Fig. A.6)	1	0	100	7	12	22	9	12	0	3.11	3	59	107	5	19	126	18	22	5	1980	0.818	193
Test Session 4	Build (Fig. A.7)	1	0	100	183	18	14	6	43	0	1.89	2	4	13	4	425	438	25	27	5	3375	0.926	500
	Play (Fig. A.8)	1	0	100	170	38	13	13	32	0	1.87	7	47	115	0	0	115	26	33	5	4290	0.788	500
Test Session 5	Build (Fig. A.9)	2	4	96	52	72	30	31	18	0	2.46	3	5	22	5	91	113	16	29	10	4640	0.552	500
	Play (Fig. A.10)	2	34	66	0	1	0	0	140	0	4.98	7	24	37	4	16	53	16	14	10	2240	1.143	702
Test Session 6	Build (Fig. A.11)	1	0	100	52	26	12	8	47	0	2.81	4	65	153	6	31	184	23	24	5	2760	0.958	407
	Play (Fig. A.12)	1	0	100	14	14	4	2	9	0	2.49	1	95	98	0	0	98	12	12	5	720	1.000	107
Test Session 7	Build (Fig. A.13)	2	17	83	0	0	2	1	87	0	4.94	2	6	10	1	6	16	19	16	10	3040	1.188	450
	Play (Fig. A.14)	1	0	100	0	0	0	0	22	0	5.00	1	79	12	0	0	12	8	6	5	240	1.333	110
Test Session 8	Build (Fig. A.15)	2	7	93	75	6	12	4	67	0	2.89	1	32	64	0	0	64	25	25	10	6250	1.000	500
	Play (Fig. A.16)	2	33	67	27	7	5	6	9	0	2.31	2	80	27	0	0	27	13	12	10	1560	1.083	125
Test Session 9	Build (Fig. A.17)	1	0	100	0	0	0	0	100	0	5.00	0	0	0	0	0	0	16	22	5	1760	0.727	500
	Play (Fig. A.18)	1	0	100	0	0	1	0	0	71	6.94	1	62	48	1	22	70	18	19	7	2394	0.947	500
Test Session 10	Build (Fig. A.19)	1	0	100	27	4	1	23	24	0	3.16	0	0	0	1	25	25	7	25	5	875	0.280	250
	Play (Fig. A.20)	2	21	79	44	37	33	14	40	0	2.82	1	82	636	0	0	636	33	32	10	10560	1.031	473
Test Session 11	Build (Fig. A.21)	1	0	100	0	0	0	0	92	0	5.00	0	0	0	0	0	0	14	25	5	1750	0.560	460
	Play (Fig. A.22)	1	0	100	0	0	0	0	100	0	5.00	0	0	0	0	0	0	19	27	5	2565	0.704	500
Test Session 12	Build (Fig. A.23)	2	46	54	0	0	0	1	91	0	4.99	1	2	1	0	0	1	10	7	10	700	1.429	459
	Play (Fig. A.24)	1	0	100	119	40	8	1	0	0	1.35	1	100	518	0	0	518	37	33	4	4884	1.121	227

Table 4.1 (continued): Playtesting data.

Playtests		Evaluation Criteria																					
Test Session #	Application Mode	Level Count (LC)	Distribution of blocks on levels (DB)		Height variation in the scene (WV)							Roof element count (RC)	Roof coverage ratio (%) (RR)	Total area of roof (AR)	Closed spaces without roof (CC)	Total area of unroofed closed spaces (AC)	Total area of roofed and unroofed closed spaces (AV= AR + AC)	Bounding box size (BB)				Horizontal and vertical sprawl ratio (XY)	Total count of blocks in scene (TB)
			Top level (%)	Bottom level (%)	Number of walls with block heights indicated below						Average wall height in scene							X direction	Y direction	Z direction	Volume (X*Y*Z)		
					1 Block	2 Blocks	3 Blocks	4 Blocks	5 Blocks	5+ Blocks													
Test Session 13	Build (Fig. A.25)	1	0	100	74	16	15	4	12	0	1.88	4	90	232	0	0	232	25	25	5	3125	1.000	227
	Play (Fig. A.26)	1	0	100	0	0	9	2	33	0	4.55	1	86	60	0	0	60	11	12	5	660	0.917	200
Test Session 14	Build (Fig. A.27)	1	0	100	2	1	14	35	35	94	5.45	5	38	97	0	0	97	21	32	7	4704	0.656	1000
	Play (Fig. A.28)	1	0	100	1	14	45	59	15	61	4.52	7	42	150	0	0	150	36	29	7	7308	1.241	882
Test Session 15	Build (Fig. A.29)	1	0	100	0	0	0	1	0	37	5.94	4	40	18	1	1	19	7	10	6	420	0.700	226
	Play (Fig. A.30)	1	0	100	0	0	0	0	73	0	5.00	0	0	0	2	94	94	16	13	5	1040	1.231	365
Test Session 16	Build (Fig. A.31)	2	37	63	223	33	14	7	30	0	1.66	4	19	88	10	353	441	23	32	10	7360	0.719	500
	Play (Fig. A.32)	2	31	69	12	26	19	7	64	0	3.66	5	28	26	1	13	39	25	14	10	3500	1.786	469
Test Session 17	Build (Fig. A.33)	2	28	72	0	0	0	0	99	0	5	1	85	135	1	1	136	17	21	10	3570	0.810	495
	Play (Fig. A.34)	2	36	64	2	0	1	0	95	0	4.90	2	15	20	3	30	50	11	19	10	2090	0.579	480
Test Session 18	Build (Fig. A.35)	2	60	40	4	12	5	3	94	0	4.45	3	25	30	3	38	68	19	15	10	2850	1.267	525
	Play (Fig. A.36)	2	44	56	2	17	10	2	85	0	4.30	4	50	57	1	6	63	18	18	10	3240	1.000	500
Test Session 19	Build (Fig. A.37)	1	0	100	5	3	5	7	67	0	4.47	4	68	25	0	0	25	16	17	5	1360	0.941	389
	Play (Fig. A.38)	1	0	100	0	0	0	0	58	0	5.00	3	4	8	2	18	26	11	13	5	715	0.846	240
Test Session 20	Build (Fig. A.39)	1	0	100	29	9	4	2	78	0	3.75	2	5	9	1	173	182	18	23	5	2070	0.783	457
	Play (Fig. A.40)	1	0	100	0	0	0	0	89	0	5.00	2	33	58	1	17	75	19	16	5	1520	1.188	445
Arithmetic (Mean) Average	Build mode	1.50	13.15	86.85	39.60	18.95	11.10	9.70	54.65	6.55	3.79	2.55	32.40	65.80	1.90	60.70	126.50	19.00	21.20	7.55	3130.40	1.02	467.25
	Play mode	1.40	11.60	88.40	20.00	10.45	8.75	6.50	49.55	6.60	4.09	2.85	45.55	100.80	1.05	15.45	116.25	18.70	18.95	7.15	2809.80	1.02	389.50
Highest Value	Build mode	2	60	100	223	170	59	57	100	94	5.94	8	91	232	10	425	441	31	32	10	7360	3.714	1000
	Play mode	2	44	100	170	40	45	59	140	71	6.94	8	100	636	5	94	636	37	33	10	10560	1.79	882
Lowest Value	Build mode	1	0	40	0	0	0	0	0	0	1.66	0	0	0	0	0	0	7	7	5	420	0.28	226
	Play mode	1	0	56	0	0	0	0	0	0	1.35	0	0	0	0	0	0	8	6	4	240	0.58	107

In this part, we will analyze the scenes created in both modes of Snaris with the framework laid out in Chapter 3.2. We will focus on twelve criteria in total, with some having several sub-parts, as seen in the table above.

(LC) On start-up, the application will start building the blocks on the first level by default, regardless of the mode of operation. The data shows that more participants explored switching to the upper level in Build Mode. In Build Mode, ten participants out of 20 explored the second level, whereas, in Play Mode, only eight players switched to the default level. This result is expected for several reasons: First, the lack of risk and reward mechanics and an unimpeded appearance of the game environment in Build Mode create a situation that encourages players to pursue more unconventional actions during the session. Second, many participants remarked that they had an agenda to model a structure (such as a castle, pool, or tower) in Build Mode. This predisposition might cause players to meddle with the game's limited control scheme and space generation abilities. Third and most importantly, in Play Mode, participants were focused on gaining the most points while trying not to collide with a previously deployed block, avoiding enclosing red objects (negative points), and avoiding overlapping with green objects since colliding with them made the point object disappear. Since players were substantially more challenged and preoccupied in Play Mode, fewer participants took the risk to switch levels as an expected result.

Figure 4.2 : An interior view from test session 3 (Build Mode).

(DB) As mentioned above, the default starting level on start-up is the bottom level, regardless of the mode of operation. Block count in the bottom level in all Play Mode scenes prevailed almost eight times compared to the upper level, whereas almost six times in scenes created in Build Mode. Most top-heavy Build Mode compositions comprise 60% of blocks in the scene at the top level, compared to 44% in Play Mode. 22 of all 40 scenes did not contain any block at the top level.

In addition to the game's guidance of initial level selection, we can speculate that human's natural preconception of bottom-heavy structures might explain the results.

(WV) The count of walls with different heights in a scene indicates height variation. This metric reveals how often participants use the next-line function during playtime.

In Build Mode, five-block tall walls are the most common. They were followed by one, two, three, four, and six blocks in height, respectively. Five-block walls are the most prevalent in Play Mode but with a greater margin. They are followed by walls one block in height and two, three, six, and four blocks in height, respectively. The distribution of wall height across the two modes is shown below.

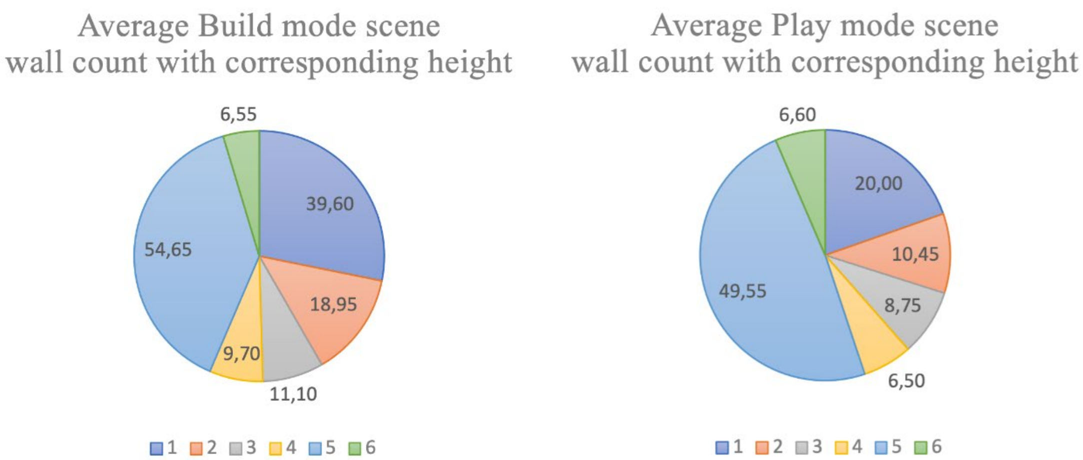

Figure 4.3 : Wall height comparison in the average scene in both modes.

The average wall height in Play Mode is about 8% higher, resulting in 3.59, compared to 3.79 in Build Mode. Also, the minimum and maximum average elevations observed in Build Mode are test sessions number 16 and 15, respectively. In Play Mode scenes, the lowest and tallest average wall heights are test sessions number twelve and nine, respectively. We also observed that certain people in the test group prefer to build relatively short or long structures, regardless of the mode of application.

(RC) Enclosing the space with a roof and a slab is one of the distinctive mechanics of the game. According to the playtesting data, at least one roof element is created in thirty-five out of forty scenes during the playtests, regardless of the mode of application. The average roof count -or enclosed space- in Play Mode is about %11 higher, reaching 2.85, compared to 2.55 in Build Mode. While the maximum number of roofs created in a scene totals up to eight across all playtests.

(RR) Roof coverage ratio is another aspect we can investigate in a scene created in Snaris. This ratio is determined by the area of the enclosed space divided by the total composition area (in the top view). Each level is considered distinctly, so overlapping levels in the top view will not skew the data. In this regard, Play Mode substantially created more enclosed space by ratio, as the scenes in Play Mode were, on average, almost half enclosed, whereas about a third were covered in Build Mode.

This result might be expected since, in Play Mode, our only goal is to get higher points only by enclosing a space. In Build Mode, participants might pursue more varied outcomes without worrying about a collision with a previous wall or acquiring game points. Thus, this freedom of agency might be the culprit for creating fewer enclosed spaces in Build Mode.

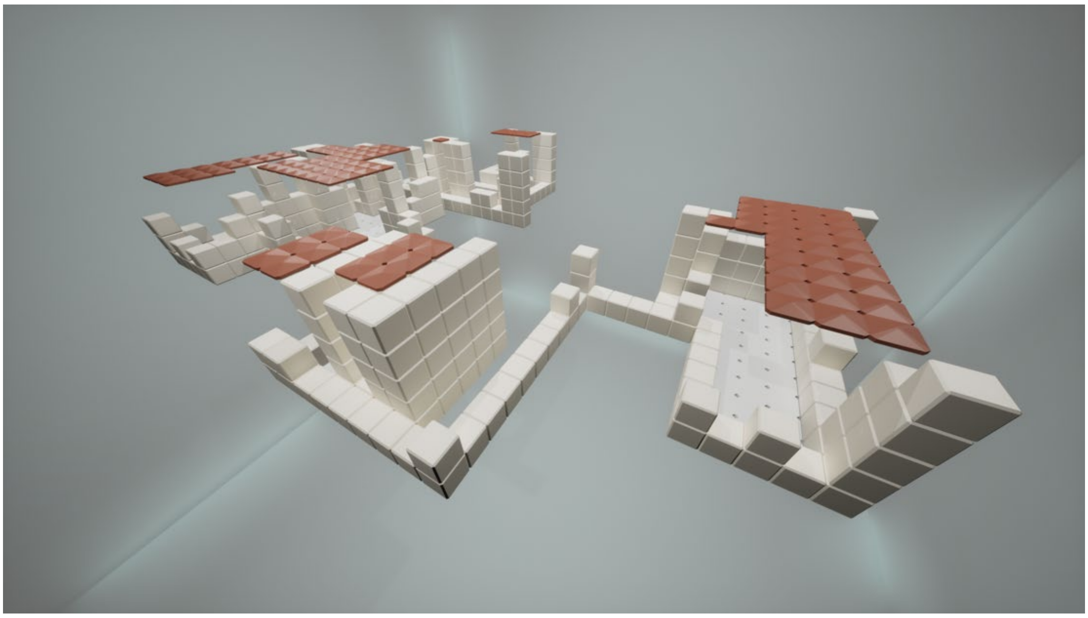

Figure 4.4 : Perspective view of test scene 4 (Play Mode).

(AR) However, regarding the total number of roof tile generation, Play Mode became prevalent by %53. As we observed in the previous criteria, participants generated fewer closed spaces and a coverage ratio in Build Mode on average. In terms of the total area of cells with a roof on top, the average Build Mode session generated 65,80 tiles, compared to 100,80 in Play Mode.

(CC) As mentioned above, enclosing the space with a roof element works if the algorithm detects a continuous wall at least one block tall surrounding at least one square of space. Chapters 3.1 and 3.2 mention that the room closure mechanic is somewhat buggy and only usually works as intended. This unintentional feature, however, gave the idea to differentiate closed spaces with and without roofs when analyzing spatial compositions.

In this regard, 17 out of 40 scenes did not accommodate any closed space lacking a roof. Eight of them are in Build Mode, and nine of them are created in Play Mode. The maximum count of unroofed tiles (CC) in a scene is ten in Build Mode versus five in Play Mode. However, on average, closed spaces without a roof occurred more frequently in Build Mode. 1.90 times, to be exact. Whereas 1.05 in Play Mode. The culprit may be the fact that participants tried to create more complex geometries that incorporate both concave and convex angles looking from the top view, which, in fact, created problems for the algorithm to detect the closed space.

(AC) In previous criteria, we discussed and commented on the count of closed spaces that happened to have no roof on top. In this criterion, we measure the total cell areas of these spaces across a given scene. So, again, 17 out of 40 scenes did not have such spaces. On average, Build Mode created 60,70 cells of closed spaces without a roof, whereas 15,45 cells were in Play Mode.

However, it is important to note that the Build Mode composition in test session four created an unusually high result: 425 cells without a roof, which skewed the average data by a considerable amount, followed by test sessions 16 and 20, which harbored 353 and 173 cells respectively. In session four, the participant created a structure resembling a defensive fort or castle with an inner group of high-rise structures surrounded by a low-rise outer wall. This kind of very large, interlocking closed spaces that incorporate concave and convex angles together cannot be detected by the algorithm reliably. This scene is shown below in Figure 4.5.

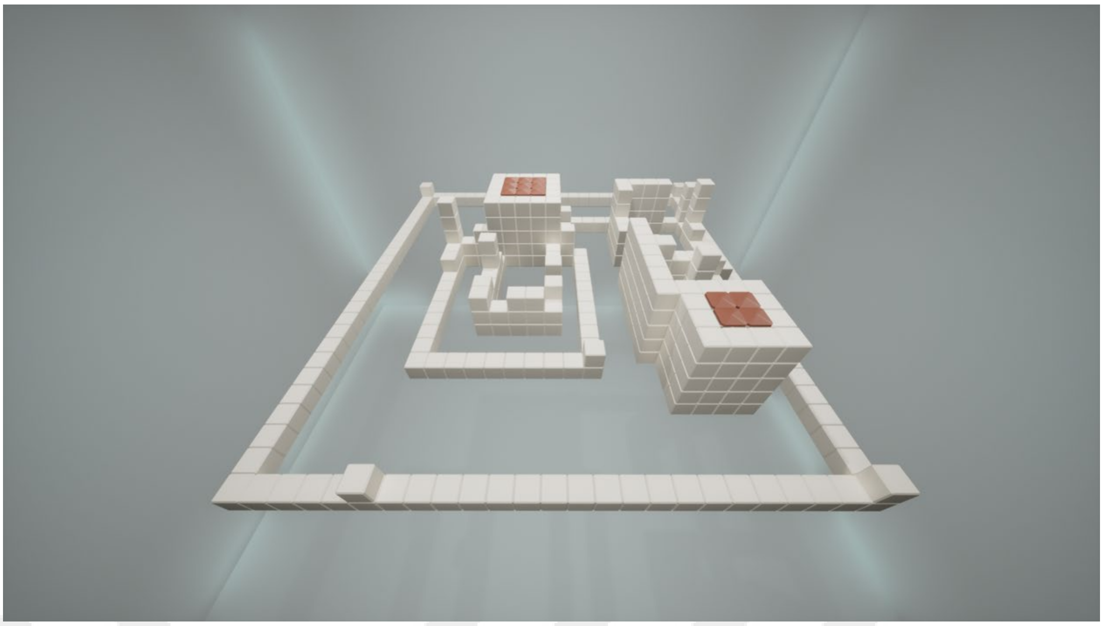

Figure 4.5 : Test scene 4 (Build Mode)

(AV) This metric is calculated by adding up previously discussed (AR) and (AC) data points. This shows us the total cell count in a scene completely surrounded by a wall, regardless of whether it is covered with a roof. In this regard, Build Mode, on average, generated 126,50 cells that are closed, whereas Play Mode generated 116,25.

(BB) A bounding, or minimal box, is a mathematical construct used mainly for computer-generated graphics. According to O'Rourke (1985), circumscribing a complex three-dimensional shape with a simpler shape is frequently advantageous for various purposes such as intersection calculations, layout, image processing, and shape analysis. The objective is to determine the smallest possible rectangular boxes that encompass a given set of N points in three dimensions, which may represent the vertices of a polyhedron. These boxes can be oriented in any way, but all their faces must meet at right angles (pp. 183).

The default direction for block stacking of Snaris is X direction. In other words, the game engine builds wall of blocks in X direction by default. The direction of wall creation will only change if the player directs new blocks another orientation. Moreover, the structures created in Snaris are orthogonal in nature. Thus, the sprawl of blocks in all directions can be easily measured. This gives us other data points for evaluating the spatial qualities of scenes created in either mode in Snaris.

The average dimension of the bounding box for the scenes generated in Build Mode is 19,00 * 21,20 * 7,55 cells for X, Y, and Z directions, respectively. For Play Mode, the dimension of the average bounding box decreases to 18,70 * 18,95 * 7,15 cells, again for X, Y, and Z directions, respectively.

The volume of a scene's bounding box is calculated by multiplying all three dimensions of the given box. In this regard, bounding boxes generated in Build Mode were slightly larger than those created in Play Mode. On average, participants created 3130,40 cell cubes of volume in Build Mode. Whereas in Play Mode, the average volume of the bounding box was only 2809,80 cell cubes, slightly smaller than in Build Mode. The average volume of bounding boxes created in Build Mode is larger because sessions are usually longer, and the total block count in the scene is slightly more than in Play Mode. This result is expected since Play Mode is a more demanding style with its added complexities. Also, substantially small structures are submitted for Play Mode with less than 1000 cell cubes in volume. This is a direct result of the participants failing early in the game by colliding with previously placed blocks.

(XY) The sprawl ratio of a built structure, looking from the top view, is another aspect we evaluated. This metric shows how wide the structure spans in the scene across right angles. The average scene in both modes turned out exactly the same, slightly wider in the X direction by just 2 percent. This parity in two distinct modes is a surprising discovery since one must enclose the space to gain points in Play Mode by creating at least four walls in all four directions (-X, +X, -Y, +Y). On the other hand, in Build Mode, participants self-appoint their agenda.

(TB) Participants generated more blocks on average in Build Mode. This is expected since, in Play Mode, the game is over if any block collides with a previous one. Since Build Mode does not incorporate a mechanic like this, a regular session in Build Mode is often longer. The total number of blocks in the scene averaged 467,25 and 389,50 in Build Mode and Play Mode, respectively.

4.3 Evaluation

In this section, we will evaluate and summarize the findings and spatial analysis laid out in the previous part. As we observed, there are remarkable differences occurred between the scenes created in both modes.

In Build Mode, the absence of risk and reward mechanics and a clear, unobstructed game environment allows players to engage in unconventional actions, harboring an atmosphere that encourages exploration and experimentation throughout the session. Another aspect of why the Build Mode created more varied outcomes is the participant's predispositions for creating a structure to resemble specific architectural typologies from the real world (i.e., castle).

In many criteria, we often observed that the players were more challenged and preoccupied during a session in Play Mode. Because of the extended ruleset and a clear goal to earn higher points, participants built differently and cautiously in Play Mode. Below, some findings regarding the differences between modes of application are summarized.

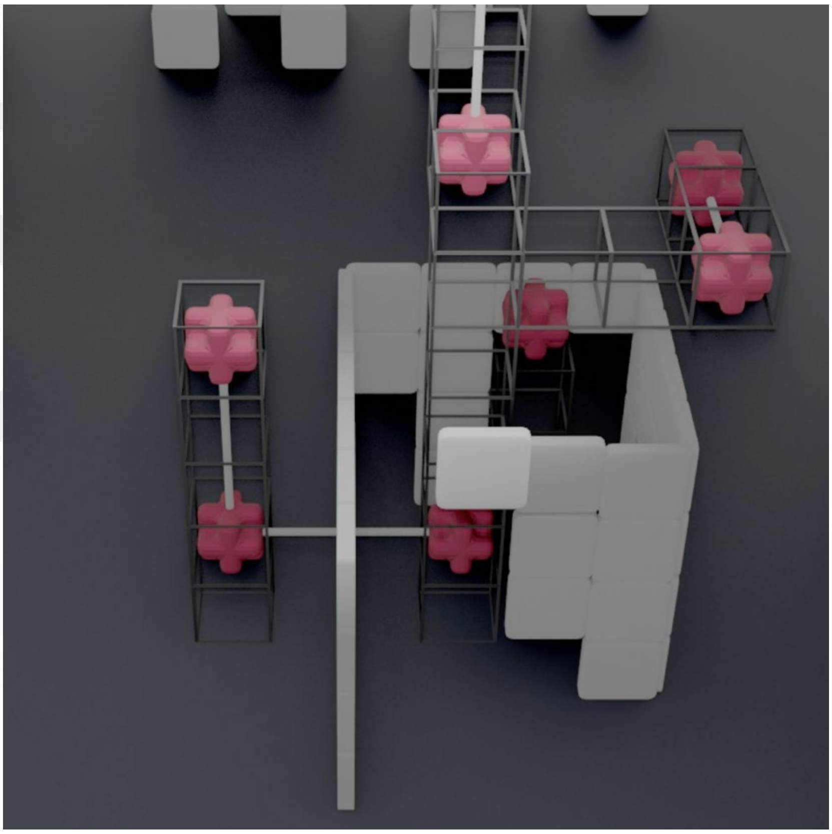

Figure 4.6 : Another iteration of the animated prototype of Snaris created in Blender.

- Switching levels were slightly less common (about 9%) in Play Mode.
- 11,60% of all blocks in a Play Mode scene were in top level, compared to 13,15% in an average Build mode scene.
- The average wall height in Play Mode is 8% higher.
- The average roof count in Play Mode is 11,7% higher, but at least one roof is created in 87,5% of playtests regardless of the Mode of application.

- Participants created fewer roofs in Build Mode, and in terms of the total area of cells with a roof on top, the average Play Mode session generated about %53 more roof cells.
- The roof coverage ratio (RR) is 40% higher in Play Mode.
- On average, closed spaces without a roof occurred almost two times more frequently in Build Mode (more complex geometries that incorporate both concave and convex angles looking from the top view created problems for the flood-fill algorithm to detect the closed space).
- In Build Mode, the average volume of bounding boxes tends to be larger compared to Play Mode. This is primarily due to the longer duration of sessions and the significantly higher total block count within the scene.
- There are substantially small structures submitted for Play Mode with less than 1000 cell cubes in volume (participants failing early in Play Mode by colliding with previously placed blocks).
- The average scene in both modes turned out exactly the same, slightly wider in the X direction by just 2 percent.
- The average scene in Build Mode had 20% more blocks placed.
- Certain people in the test group prefer to build short or long structures, regardless of the mode of application.

5. CONCLUSION

This research has shed light on the intricate and complex relationship between players' agencies and the effects of game mechanics on generating virtual environments. By recognizing the player as both the subject and object of the virtual experience (the concept of “recursive space”), we have highlighted the active decision-making process and the continuous feedback loop between the user and the virtual environment.

Our testing apparatus, Snaris, features two distinct states: Play Mode and Build Mode. Thus, creating a framework for us to isolate and analyze the involvement of rulesets of our interest in the spatial creation process. The case study enabled us to create a controlled experiment setup to compare the results from two distinct application modes to measure our research questions and evaluation criteria. In the testing stage, we completed 20 playtests, totaling 40 scenes. The author analyzed each scene using the evaluation framework elaborated in Chapter 3.2. The findings from playtests have provided valuable insights into the influence of game mechanics on player decision-making, engagement, and overall experience navigating and negotiating in virtual environments (Chapters 4.2 and 4.3). Thus, a conclusive inference can be drawn upon revisiting the research questions addressed in this study.

- How does the involvement of risk and reward mechanics impact the spatial outcomes generated by participants using a 3D puzzle game?

The risk and reward mechanics impacted the spatial outcomes created in Snaris in numerous ways. In general, participants were more preoccupied and constrained by the game’s ruleset in Play Mode; in this mode, participants switched to different levels less commonly (LC), generated more closed spaces to gain game points (RC), and achieved more roof coverage ratio (RR), built overall smaller structures due to the risk of colliding with a previously placed block (BB & TB). In Build Mode, however, participants usually strived to explore the 3D space freely. The primary discrepancies in this mode occurred due to sessions taking longer and the lack of a game point system and collision risk. On average, closed spaces without a roof (CC) occurred almost twice as frequently in Build Mode due to the participant’s reluctance to create small, simple-shaped closed rooms. Overall, the risk and reward rulesets are an essential feature of any game, a distinctive factor that differentiates games and simulations. We observed that the existence of these mechanics forced the participants to generate smaller, more incoherent, and random compositions. The participants usually had less awareness of the outcome.

- In which ways do the risk and reward mechanics affect the player's role in shaping virtual spaces? What is the impact of more challenging situations on the spatial composition in a virtual environment?

The lack of risk and reward mechanics and less challenging conditions in Build Mode often contributed to the participants' agenda to create a structure resembling real-world buildings such as castles, pools, towers, etc. In addition, participants were more conscious of what they were constructing and how the structure's final form would look. In Play Mode, on the other hand, participants were usually too busy to increase their game points and avoid collisions to be able to shape the spatial outcome deliberately. Thus, creating more random and incoherent structures in this mode. Some participants found extensive rulesets rather overwhelming, thus wanted to spend more time in Build Mode, where they can freely construct. Others found the lack of aim in Build Mode rather dull and wanted to be challenged in Play Mode. Overall, the personal preferences of participants and their varied outlook towards "games" was the determining factor for their relationship with the game and its mechanics.

- How do software limitations influence the generation of spatial elements?

The limitations of our testing apparatus (elaborated in Chapter 3.1.4) affected the spatial outcomes considerably. The creations were limited to the voxel-based, orthogonal, fixed-height (depending on the game setup) and two-level structures. In addition, although we intend to develop the application differently, the roofs were created at a fixed level depending on the game setup. The fixed block spawn direction did not allow structures resembling arches. Also, the room closure mechanic usually works as intended, especially with complex shapes involving concave and convex angles when looking from the top. However, this shortcoming gave us the idea to investigate the scenes with additional criteria like the number of unroofed closed spaces (CC), thus enabling us to evaluate the end-game results more broadly. As a deduction, if we somehow created even more options to generate spaces (such as with a toggle, blocks themselves might be manipulated on the fly, or various type of blocks constantly spawn such as in Tetris), the fun part of the game would be hindered to the point it would become too challenging for average player. Overall, limitations can be used creatively to create a fun and engaging game. Like they say, “Less is more”.

Along with the mentioned limitations of the application, the research method has shortcomings when evaluating spatial data. Namely, the limited amount of playtesting participants creates irregular data for evaluation. Also, as mentioned in Chapter 3.1.1, mobile platforms might be more idiosyncratic for this application. Thus, a prototype testing apparatus developed for PCs with limited accessibility does not provide the ideal testing conditions for this research. Although we gained some insightful deductions from this case study, the mentioned limitations affected the outcomes of this research.

5.1 Contribution of This Study

This research helped us investigate game mechanics’ role in generating virtual spaces. We designed and developed a testing apparatus to conduct playtests and evaluate resulting scenes with a bespoke framework. Thus, this study may contribute to scientific niches like game studies, human behavior in virtual spaces, architectural design, and spatial design evaluation. The custom framework for qualitatively evaluating spatial data proposed in Chapter 3.2 may contribute to future research in related fields.

This research can guide game development practices, postulating that the user and virtual space are inseparable. Users’ actions and decisions become integral parts of a complex cause-and-effect system, where each choice changes the virtual environment's state, consequently influencing their subsequent actions. This iterative process gives rise to a distinctive composition that can be summarized as a “recursive space”, as elaborated in Chapter 2. Thus, game developers can benefit from this study as a frame of reference for designing and balancing the game mechanics for their intended game.

Along with being a testbench for this research, Snaris can also be used in preliminary spatial design phases in the field of architecture. Especially in Build Mode, this application can be used as a 3D sketching tool for realizing spatial ideas using a common gaming control scheme despite the limitations of possible shapes and spaces.

5.2 Future Research and Predictions

The author considers this study a precursor to upcoming research in related fields. The application could be better developed and integrated into various platforms, more functions could be added, and a more robust space closure detection algorithm could be implemented in the future. On the evaluation side, this study employed a qualitative method to analyze the end-game scenes, requiring the author to collect and interpret the spatial data manually. However, a more automated analysis system could be implemented in this research. For example, at the end of a session, the user could analyze the spatial data by selecting from several built-in evaluation algorithms (such as those mentioned in Chapter 1.4), thus eliminating the author's bias, and streamlining the process. The scene and the spatial analysis could then be uploaded to a repository for archiving and open-source viewing. With this system, we can increase the data points gathered and create a more robust and accessible evaluation process.

In the future, game systems and the virtual environments they offer will be increasingly more complex, both to design, develop and also to experience. Dynamic game systems such as automatic difficulty adjustment on the fly will ensure the game is always balanced between too challenging and too easy, therefore more engaging to the player. For designer's perspective, we must increasingly adapt ourselves to be working with ever changing tools and Artificial Intelligence. The author believes such tools will enable us to work more efficiently and realize complex ideas, rather than replacing us. Also, in the future, the concept of player agency will extend beyond gameplay mechanics and encompass narrative experiences as well. Players will have greater influence over the direction and outcomes of storylines, leading to more personalized and interactive storytelling and experiences. Another big aspect of upcoming technologies is in the field of human-computer interaction. Technologies such as AR and VR will immerse us in virtual environments and redefine social interactions and working practices.

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APPENDICES

APPENDIX A: Test Scene 1-B (Build Mode)
APPENDIX B: Test Scene 1-P (Play Mode)
APPENDIX C: Test Scene 2-B (Build Mode)
APPENDIX D: Test Scene 2-P (Play Mode)
APPENDIX E: Test Scene 3-B (Build Mode)
APPENDIX F: Test Scene 3-P (Play Mode)
APPENDIX G: Test Scene 4-B (Build Mode)
APPENDIX H: Test Scene 4-P (Play Mode)
APPENDIX I: Test Scene 5-B (Build Mode)
APPENDIX J: Test Scene 5-P (Play Mode)
APPENDIX K: Test Scene 6-B (Build Mode)
APPENDIX L: Test Scene 6-P (Play Mode)
APPENDIX M: Test Scene 7-B (Build Mode)
APPENDIX N: Test Scene 7-P (Play Mode)
APPENDIX O: Test Scene 8-B (Build Mode)
APPENDIX P: Test Scene 8-P (Play Mode)
APPENDIX Q: Test Scene 9-B (Build Mode)
APPENDIX R: Test Scene 9-P (Play Mode)
APPENDIX S: Test Scene 10-B (Build Mode)
APPENDIX T: Test Scene 10-P (Play Mode)
APPENDIX U: Test Scene 11-B (Build Mode)
APPENDIX V: Test Scene 11-P (Play Mode)
APPENDIX W: Test Scene 12-B (Build Mode)
APPENDIX X: Test Scene 12-P (Play Mode)
APPENDIX Y: Test Scene 13-B (Build Mode)
APPENDIX Z: Test Scene 13-P (Play Mode)
APPENDIX 1-A: Test Scene 14-B (Build Mode)
APPENDIX 1-B: Test Scene 14-P (Play Mode)
APPENDIX 1-C: Test Scene 15-B (Build Mode)
APPENDIX 1-D: Test Scene 15-P (Play Mode)
APPENDIX 1-E: Test Scene 16-B (Build Mode)
APPENDIX 1-F: Test Scene 16-P (Play Mode)
APPENDIX 1-G: Test Scene 17-B (Build Mode)
APPENDIX 1-H: Test Scene 17-P (Play Mode)
APPENDIX 1-I: Test Scene 18-B (Build Mode)
APPENDIX 1-J: Test Scene 18-P (Play Mode)
APPENDIX 1-K: Test Scene 19-B (Build Mode)
APPENDIX 1-L: Test Scene 19-P (Play Mode)
APPENDIX 1-M: Test Scene 20-B (Build Mode)
APPENDIX 1-N: Test Scene 20-P (Play Mode)

APPENDIX A: Test Scene 1-B (Build Mode)

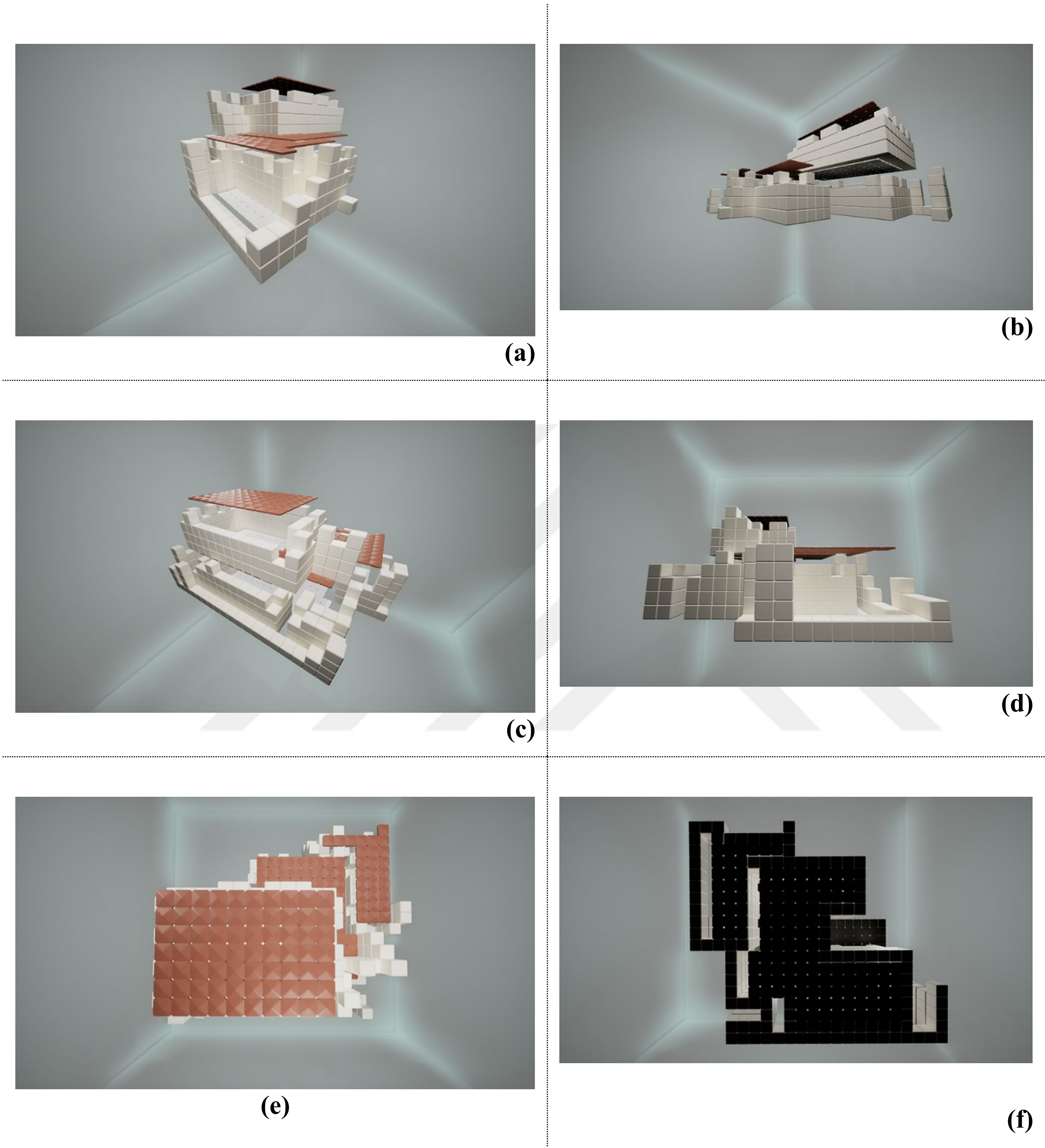


Figure A.1 : Images from test scene 1-B (Build Mode). (a), (b), (c), (d): Perspective view of the scene. (e): Top view, (f): Bottom view.

APPENDIX B: Test Scene 1-P (Play Mode)

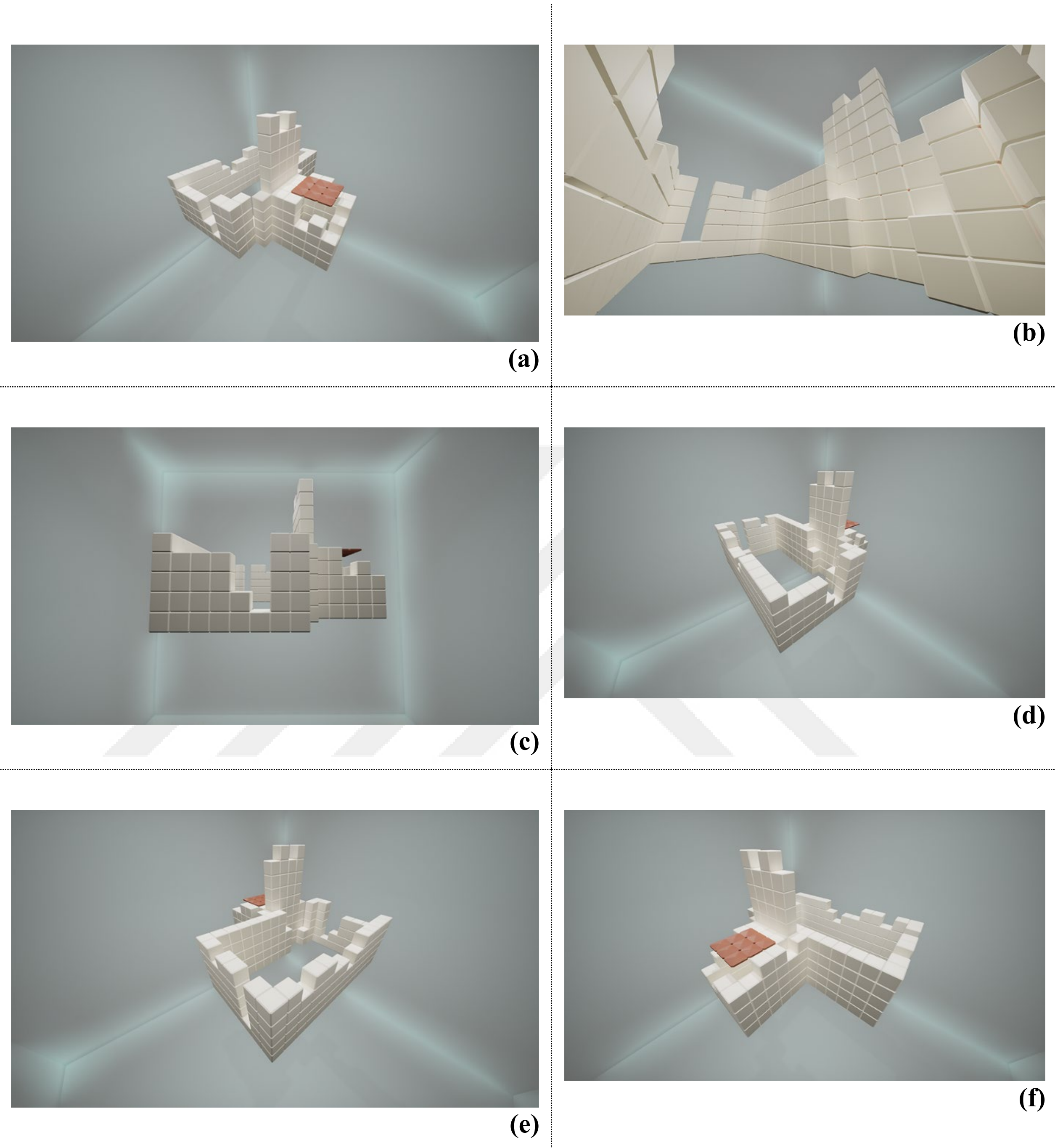


Figure A.2 : Images from test scene 1-P (Play Mode). Perspective views of the scene.

APPENDIX C: Test Scene 2-B (Build Mode)

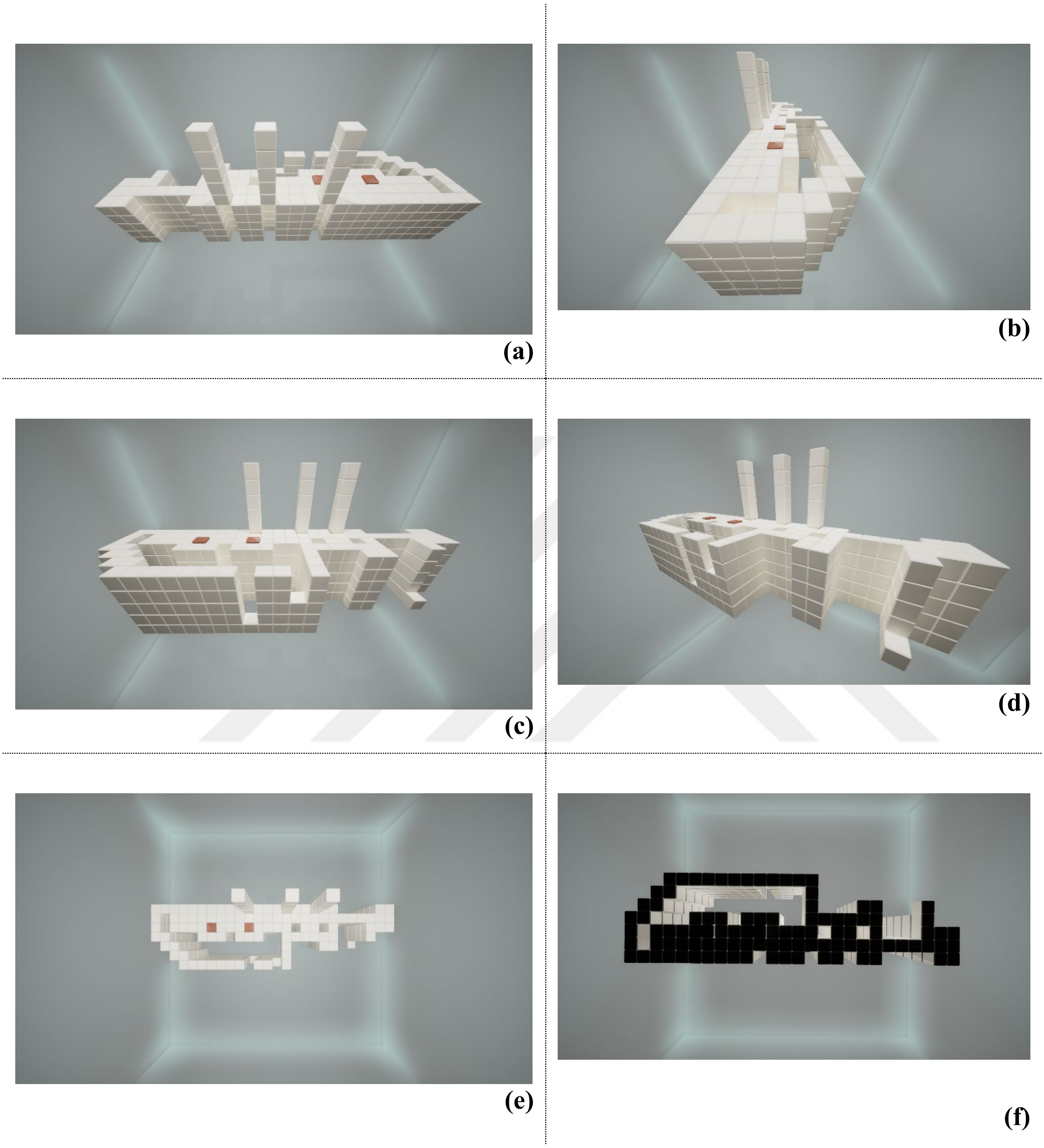


Figure A.3 : Images from test scene 2-B (Build Mode). (a), (b), (c), (d): Perspective view of the scene. (e): Top view, (f): Bottom view.

APPENDIX D: Test Scene 2-P (Play Mode)

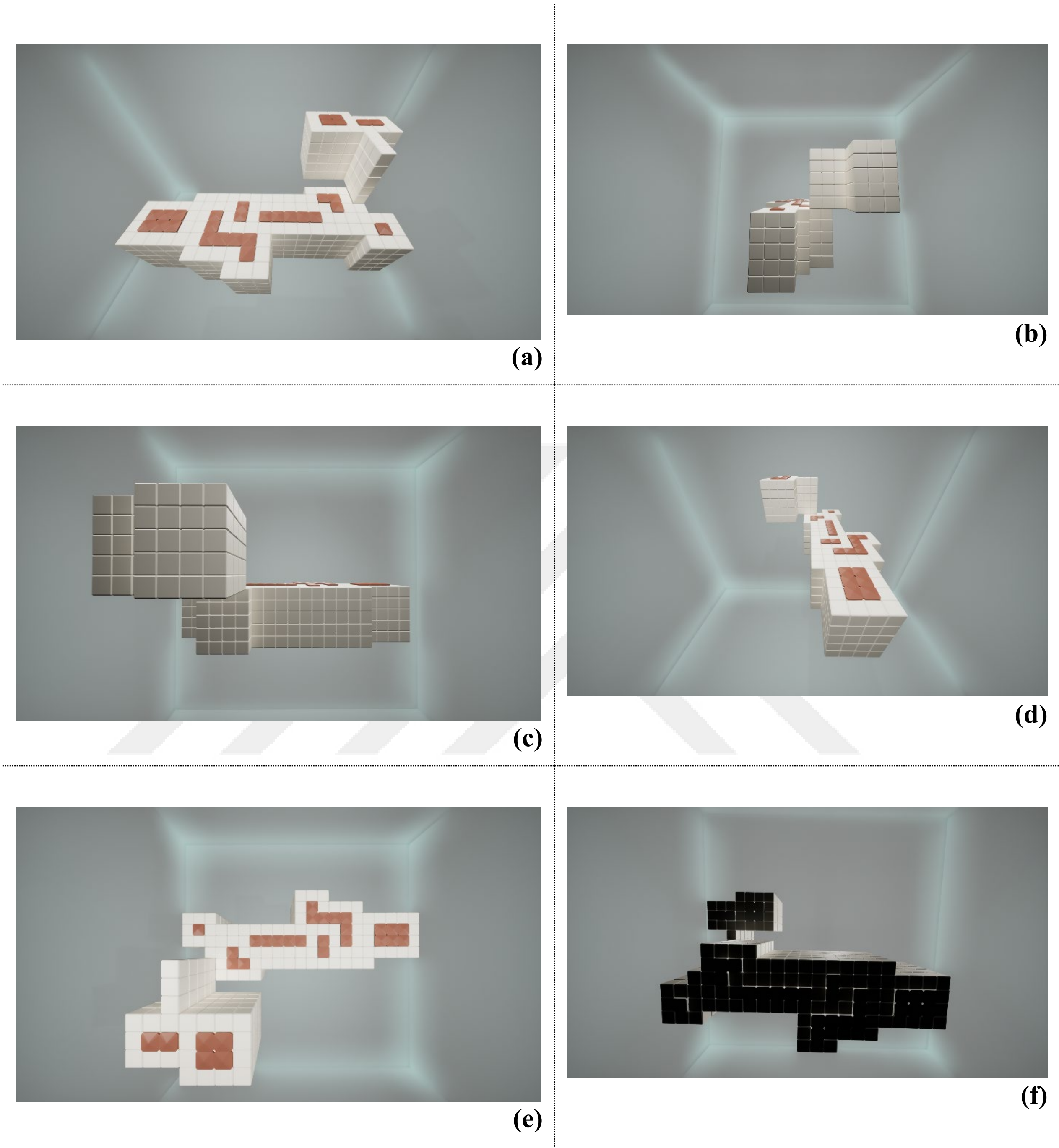
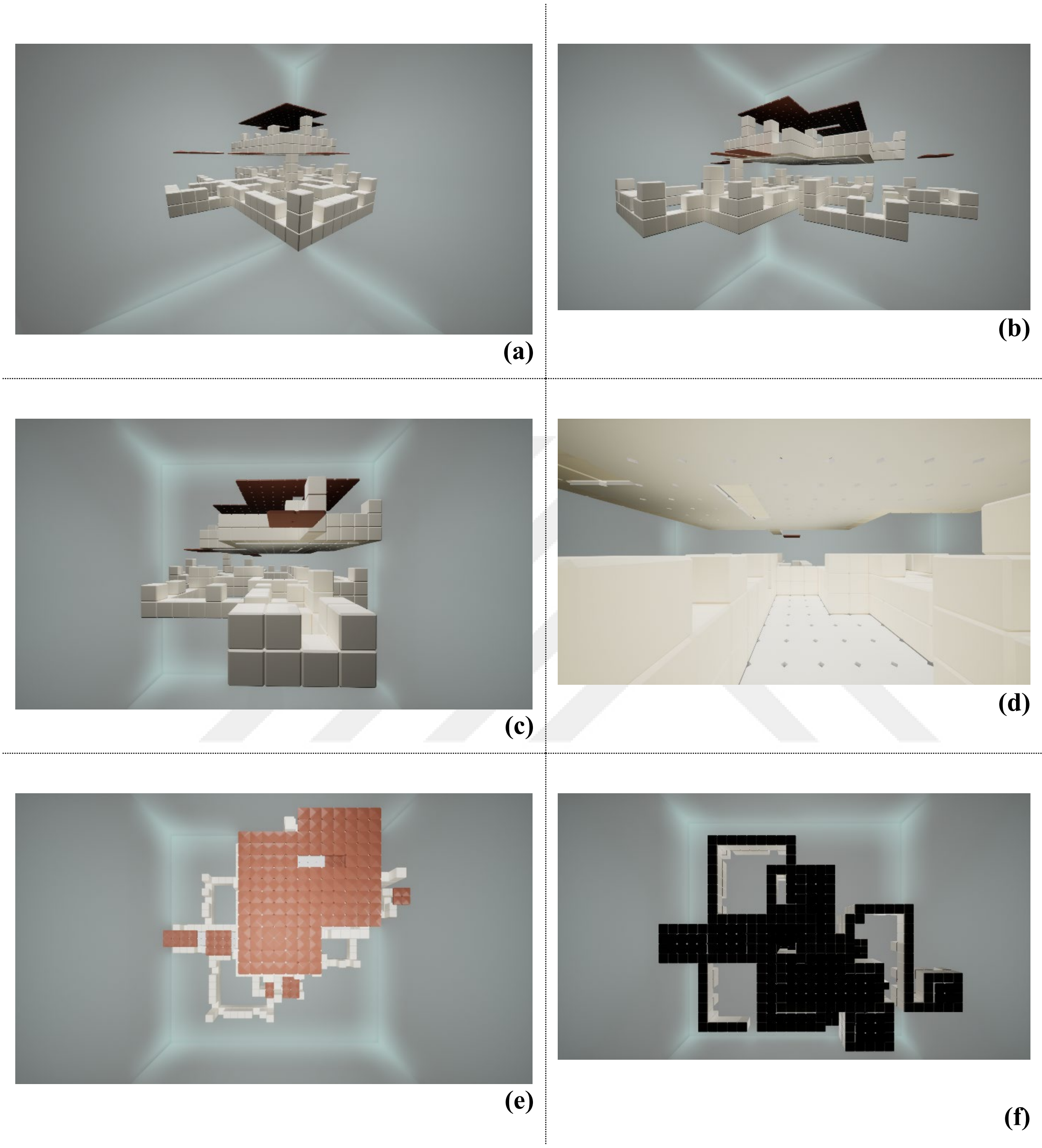


Figure A.4 : Images from test scene 2-P (Play Mode). (a), (b), (c), (d): Perspective view of the scene. (e): Top view, (f): Bottom view.

APPENDIX E: Test Scene 3-B (Build Mode)



(a) (b) (c) (d) (e) (f)

Figure A.5 : Images from test scene 3-B (Build Mode). (a), (b), (c), (d): Perspective view of the scene. (e): Top view, (f): Bottom view.

APPENDIX F: Test Scene 3-P (Play Mode)

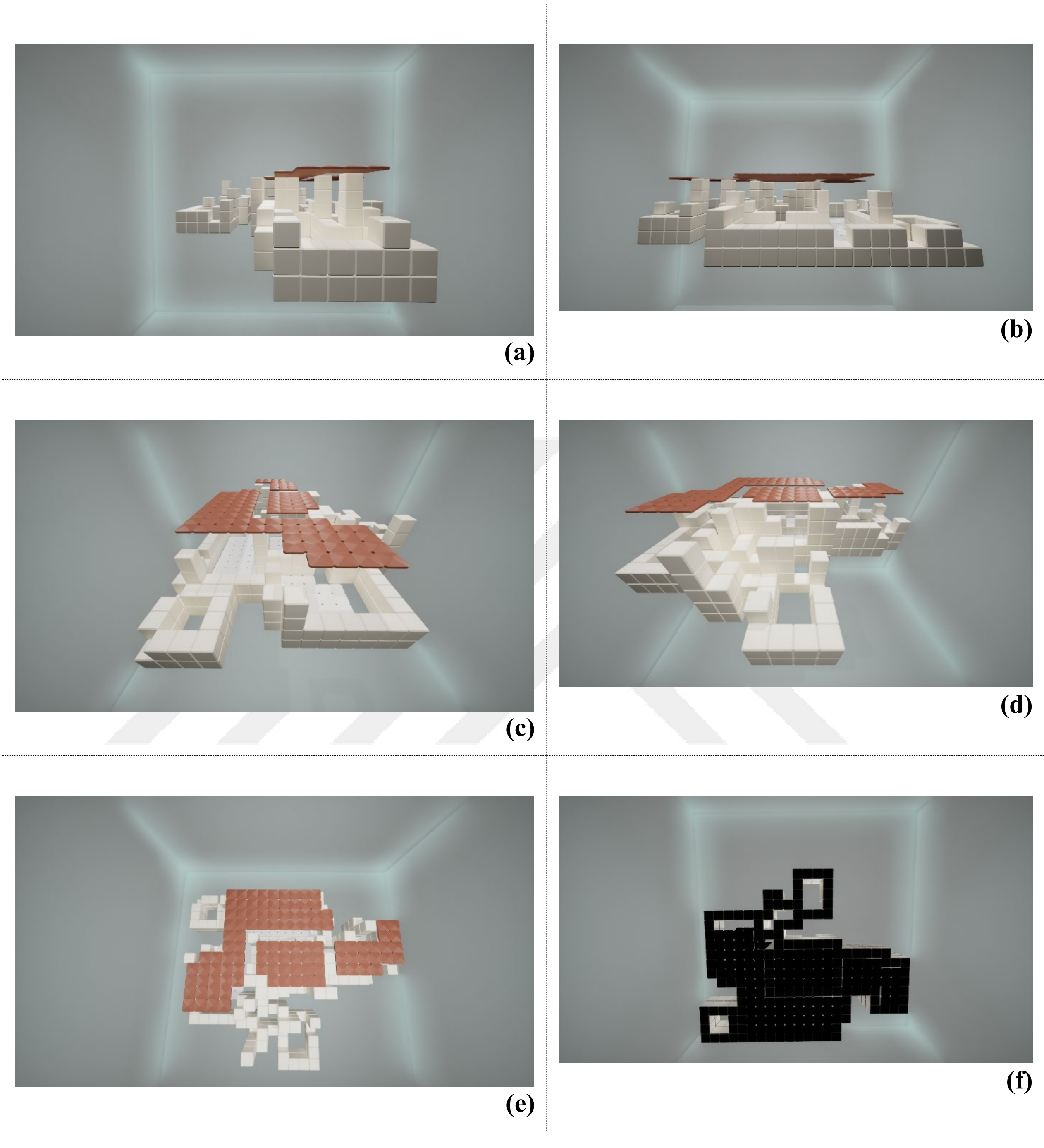


Figure A.6 : Images from test scene 3-P (Play Mode). (a), (b), (c), (d): Perspective view of the scene. (e): Top view, (f): Bottom view.

APPENDIX G: Test Scene 4-B (Build Mode)

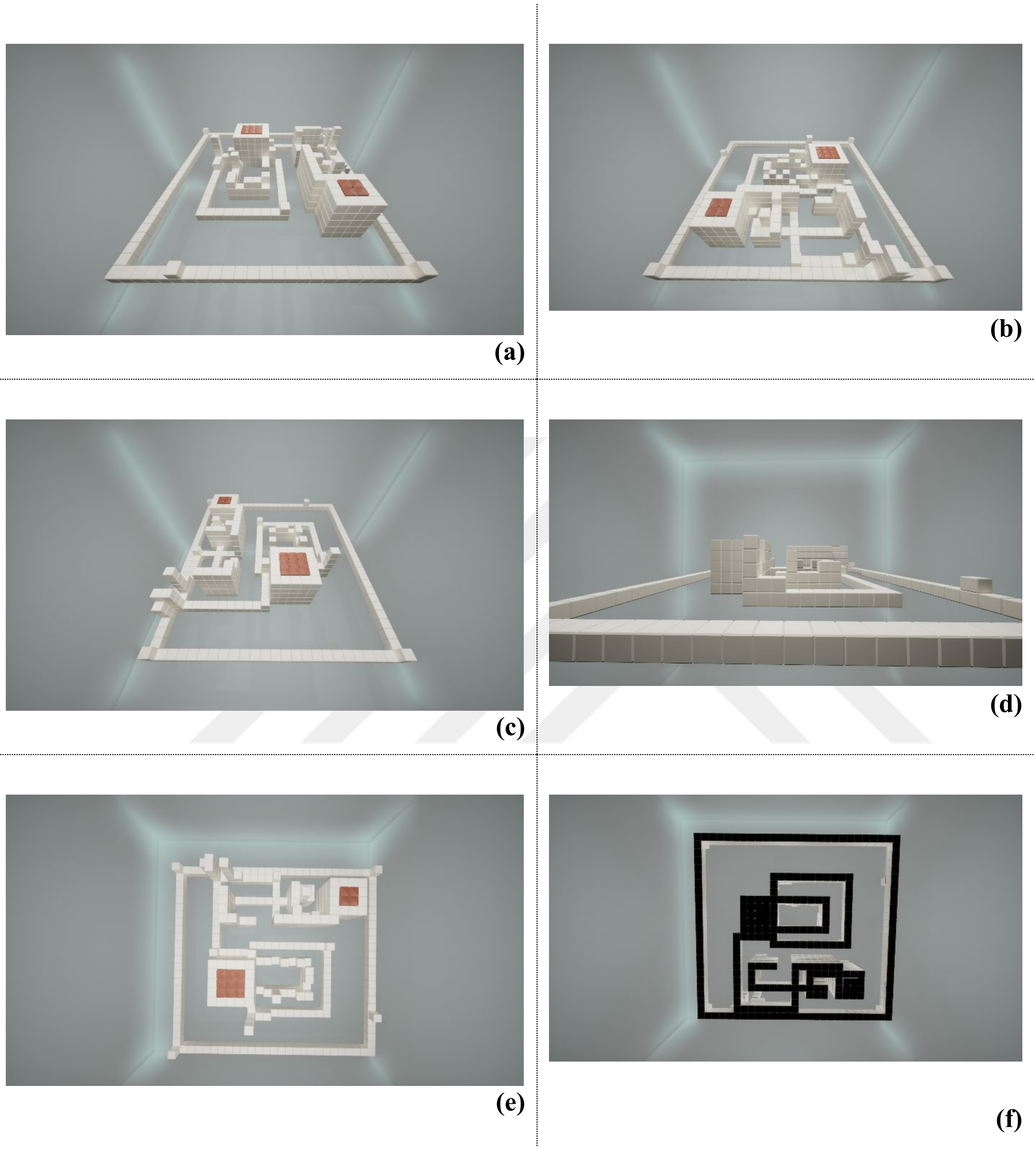


Figure A.7 : Images from test scene 4-B (Build Mode). (a), (b), (c), (d): Perspective view of the scene. (e): Top view, (f): Bottom view.

APPENDIX H: Test Scene 4-P (Play Mode)

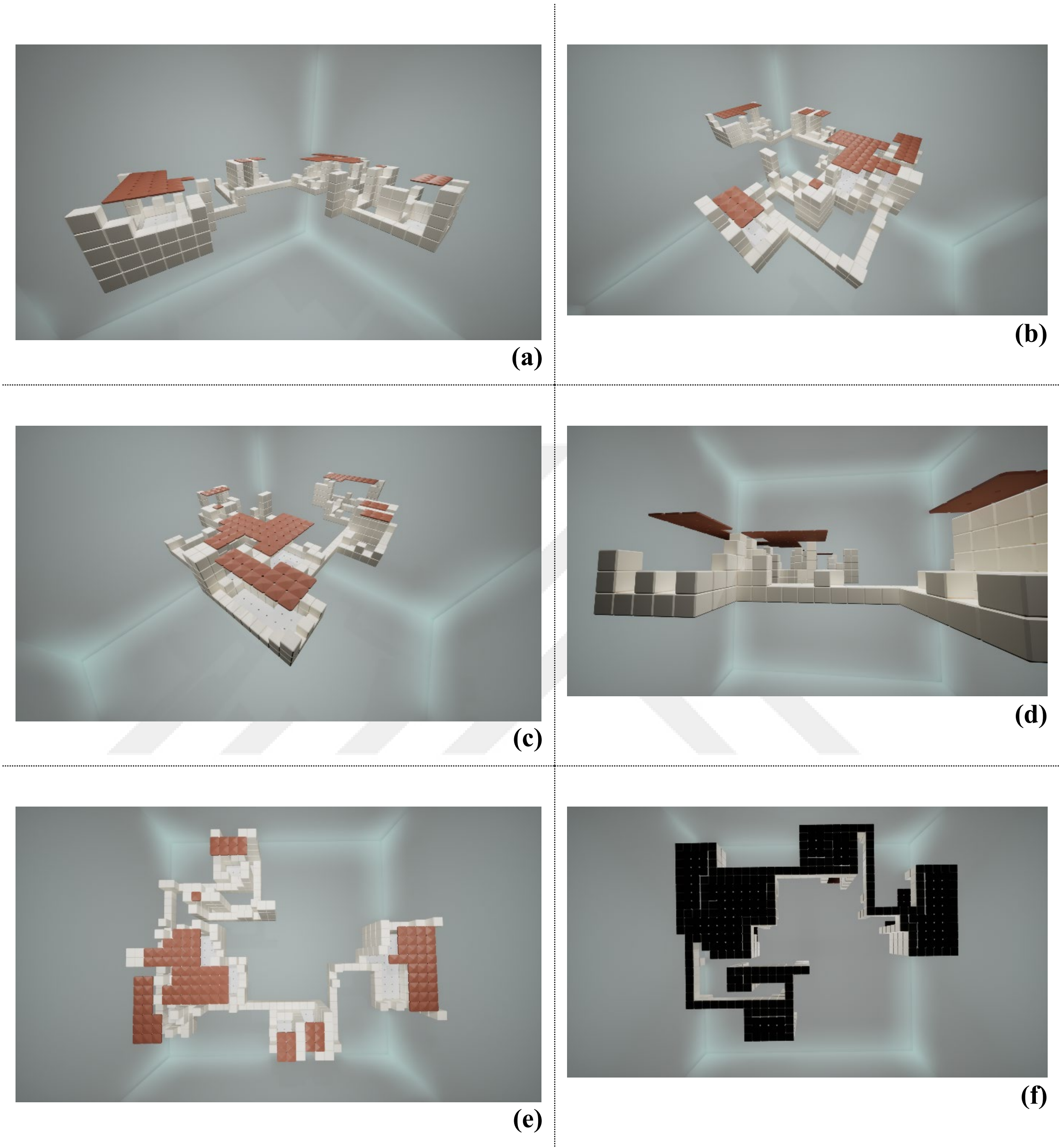


Figure A.8 : Images from test scene 4-P (Play Mode). (a), (b), (c), (d): Perspective view of the scene. (e): Top view, (f): Bottom view.

APPENDIX I: Test Scene 5-B (Build Mode)

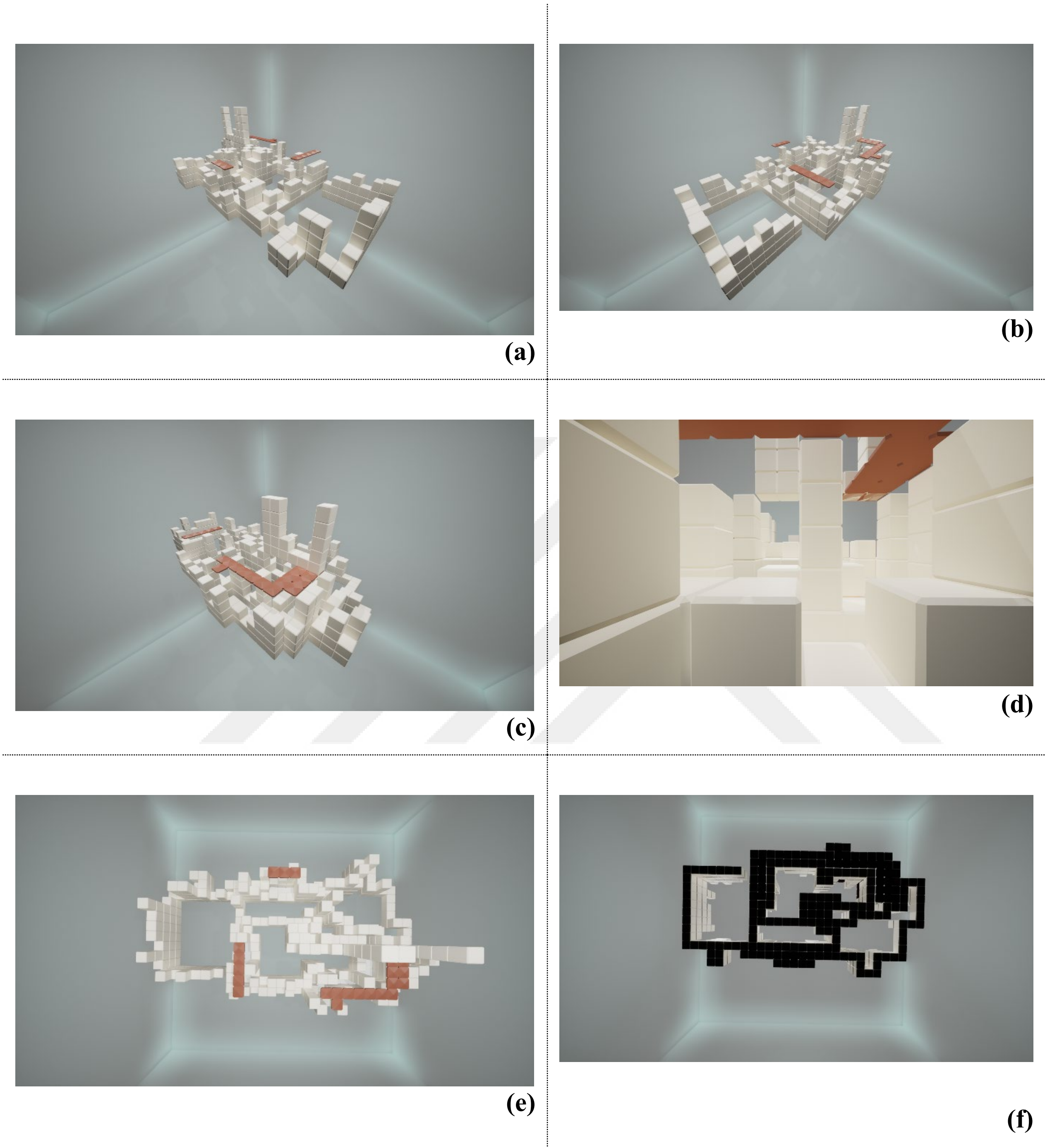


Figure A.9 : Images from test scene 5-B (Build Mode). (a), (b), (c), (d): Perspective view of the scene. (e): Top view, (f): Bottom view.

APPENDIX J: Test Scene 5-P (Play Mode)

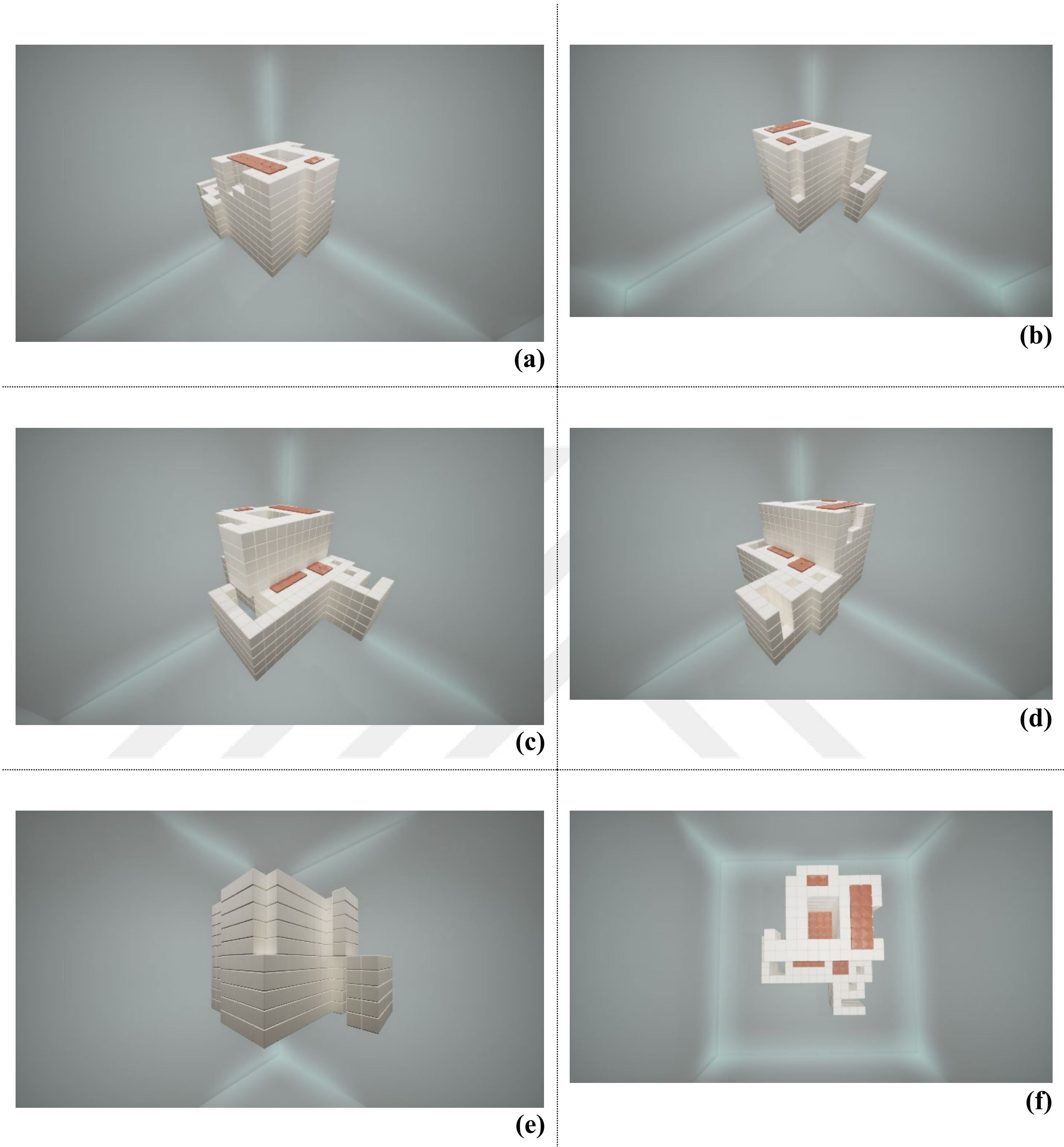


Figure A.10 : Images from test scene 5-P (Play Mode). (a), (b), (c), (d), (e): Perspective view of the scene. (f): Top view.

APPENDIX K: Test Scene 6-B (Build Mode)

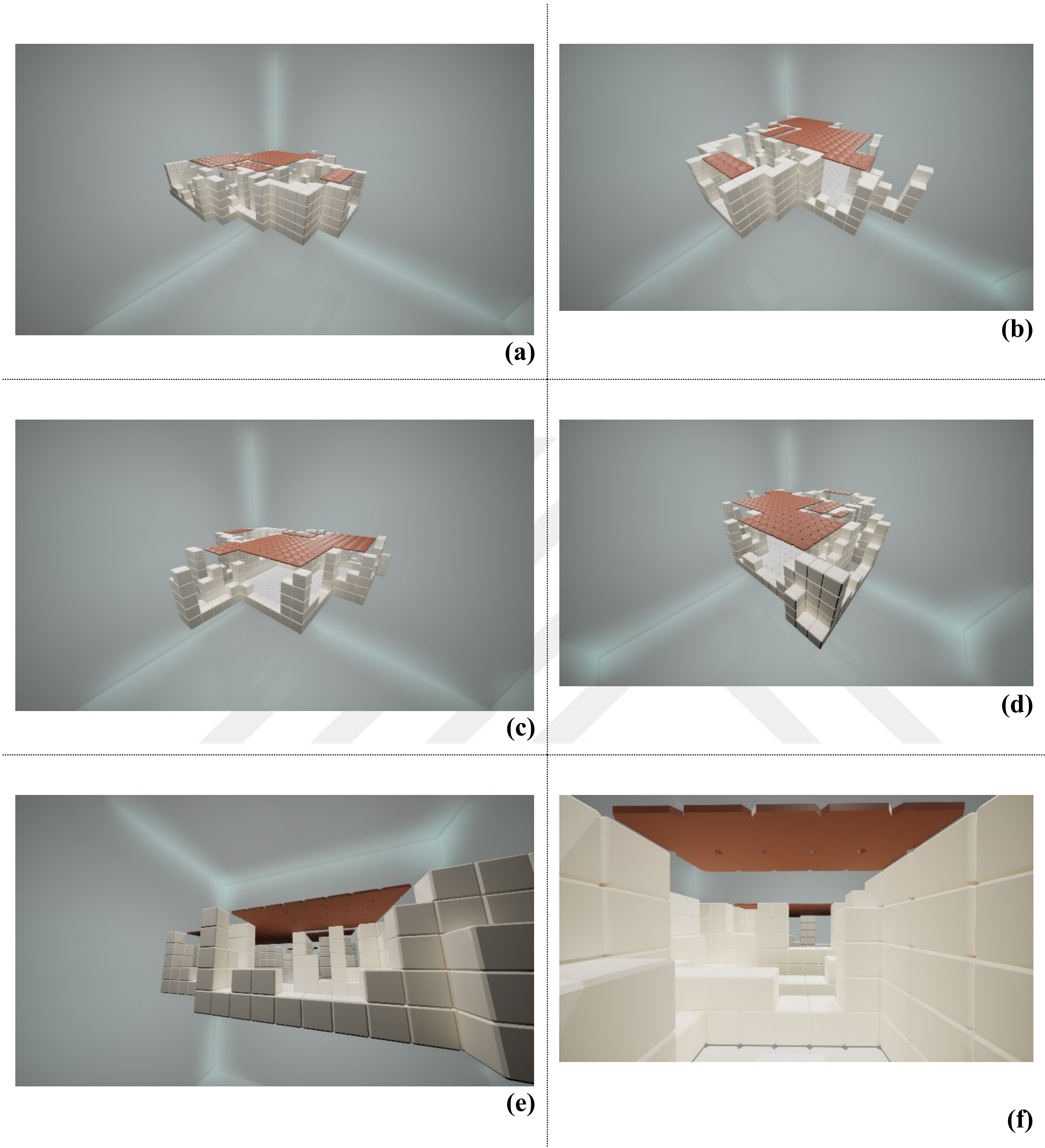


Figure A.11 : Images from test scene 6-B (Build Mode). (a), (b), (c), (d), (e), (f): Perspective view of the scene.

APPENDIX L: Test Scene 6-P (Play Mode)

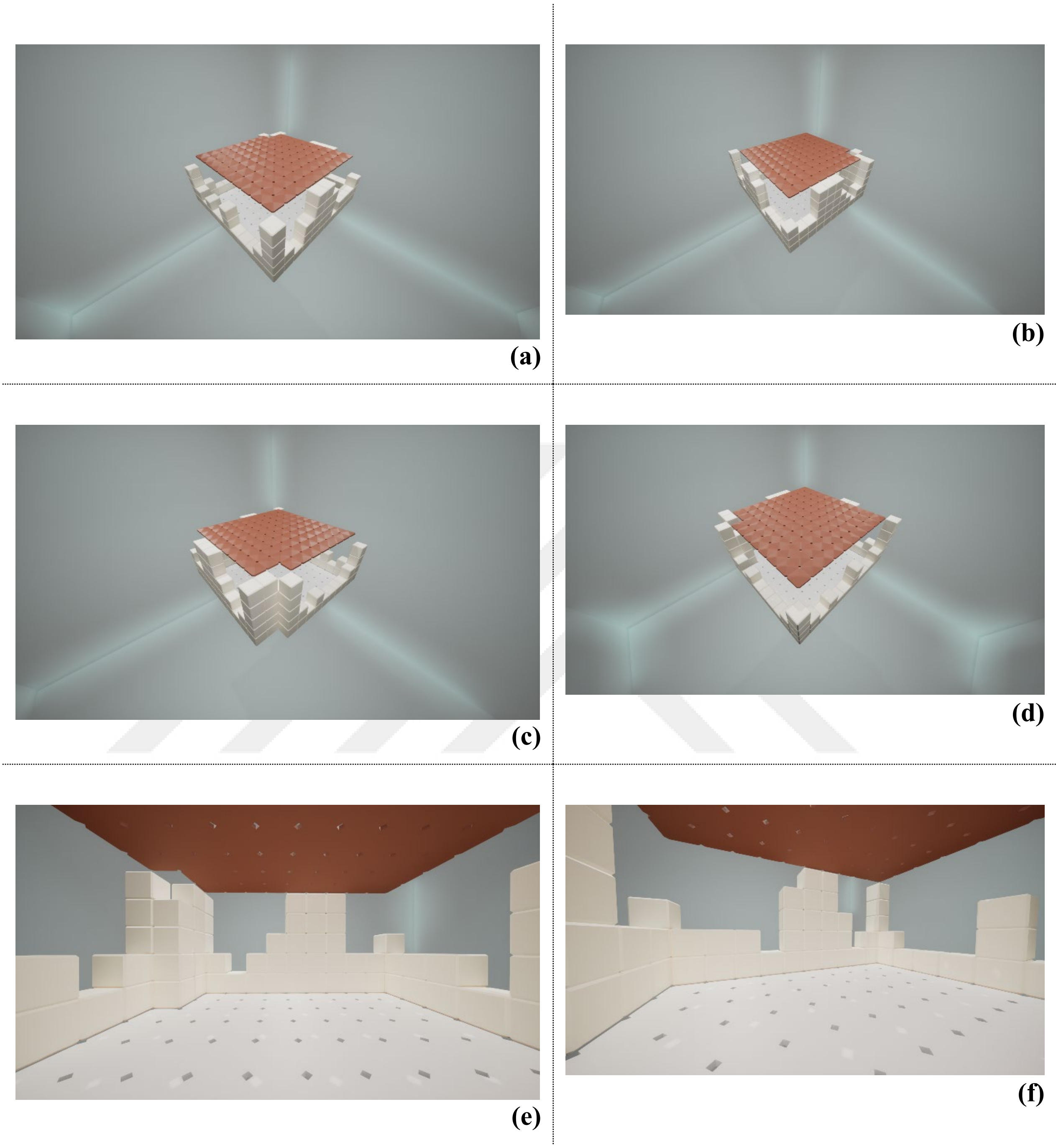


Figure A.12 : Images from test scene 6-P (Play Mode). (a), (b), (c), (d), (e), (f): Perspective view of the scene.

APPENDIX M: Test Scene 7-B (Build Mode)

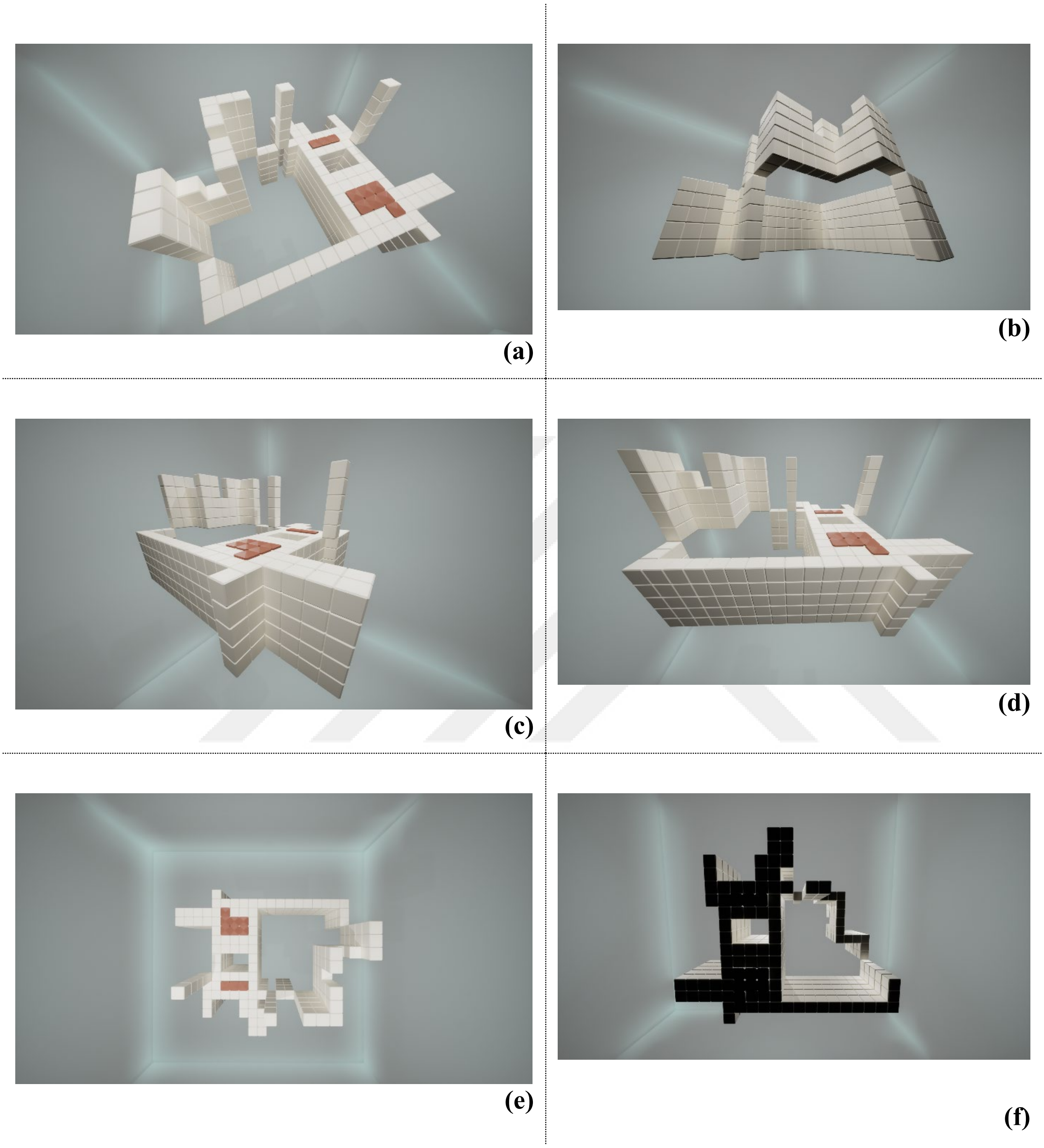


Figure A.13 : Images from test scene 7-B (Build Mode). (a), (b), (c), (d): Perspective view of the scene. (e): Top view, (f):Bottom view.

APPENDIX N: Test Scene 7-P (Play Mode)

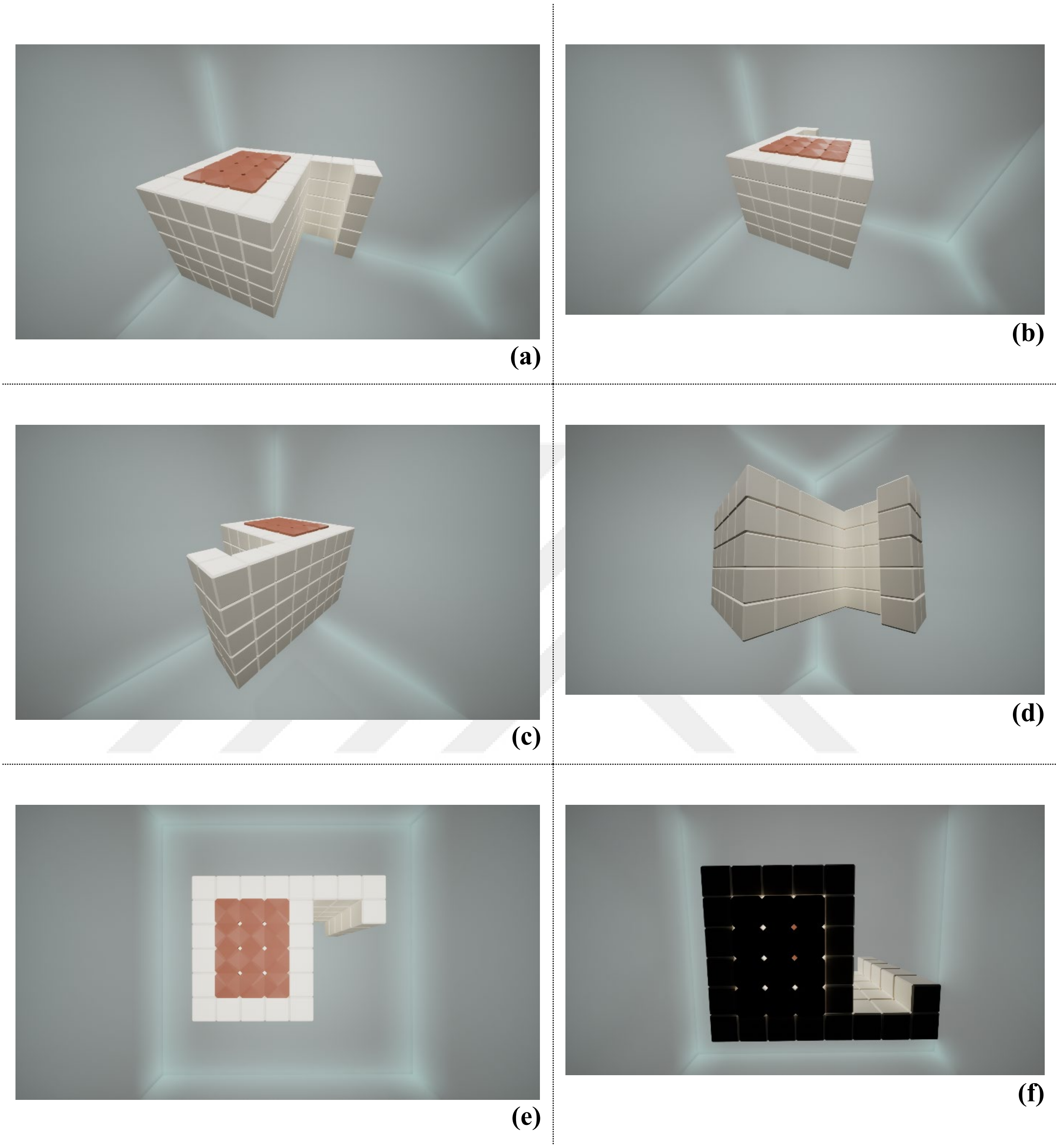


Figure A.14 : Images from test scene 7-P (Play Mode). (a), (b), (c), (d): Perspective view of the scene. (e): Top view, (f): Bottom view.

APPENDIX O: Test Scene 8-B (Build Mode)

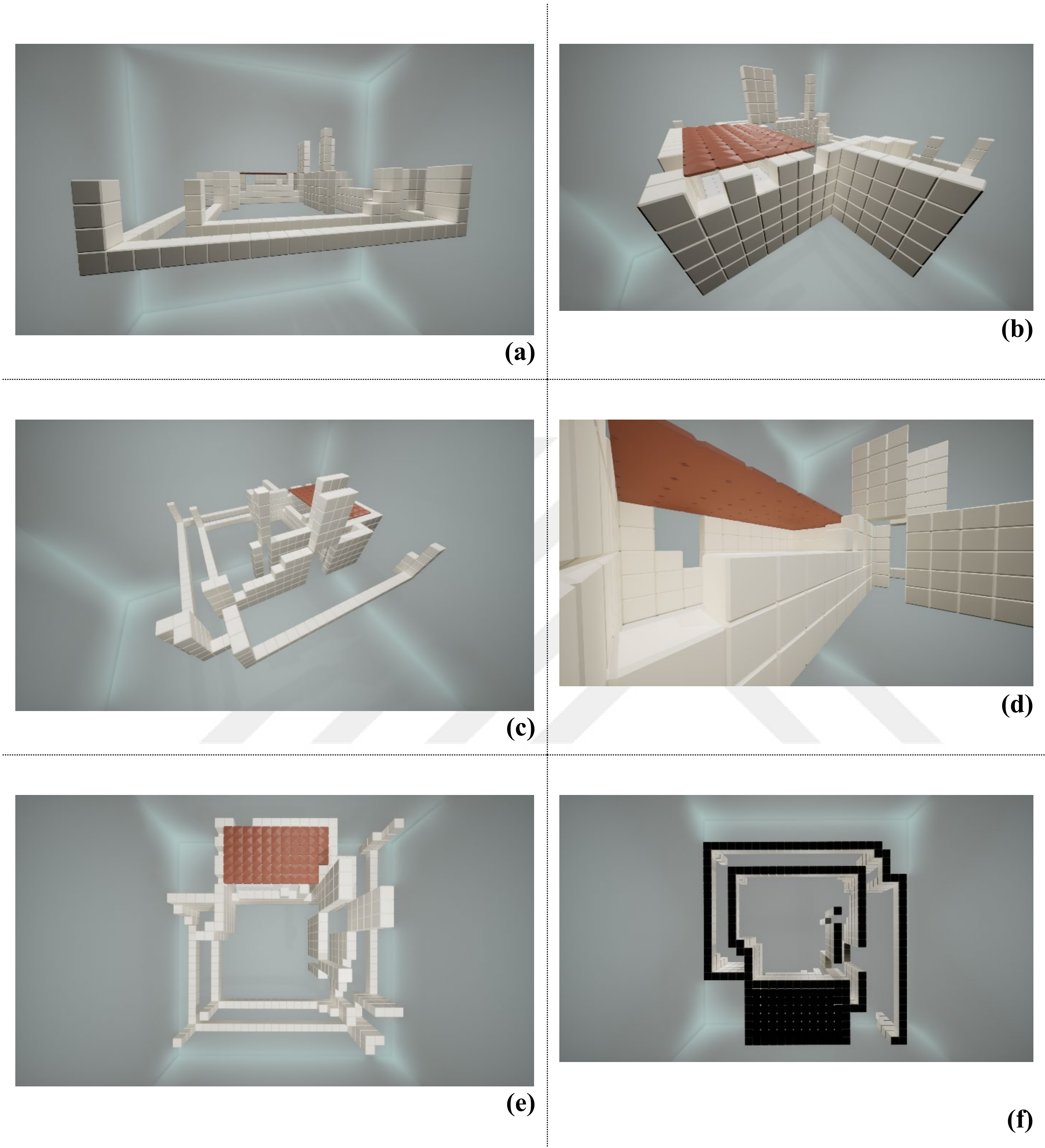


Figure A.15 : Images from test scene 8-B (Build Mode). (a), (b), (c), (d): Perspective view of the scene. (e): Top view, (f):Bottom view.

APPENDIX P: Test Scene 8-P (Play Mode)

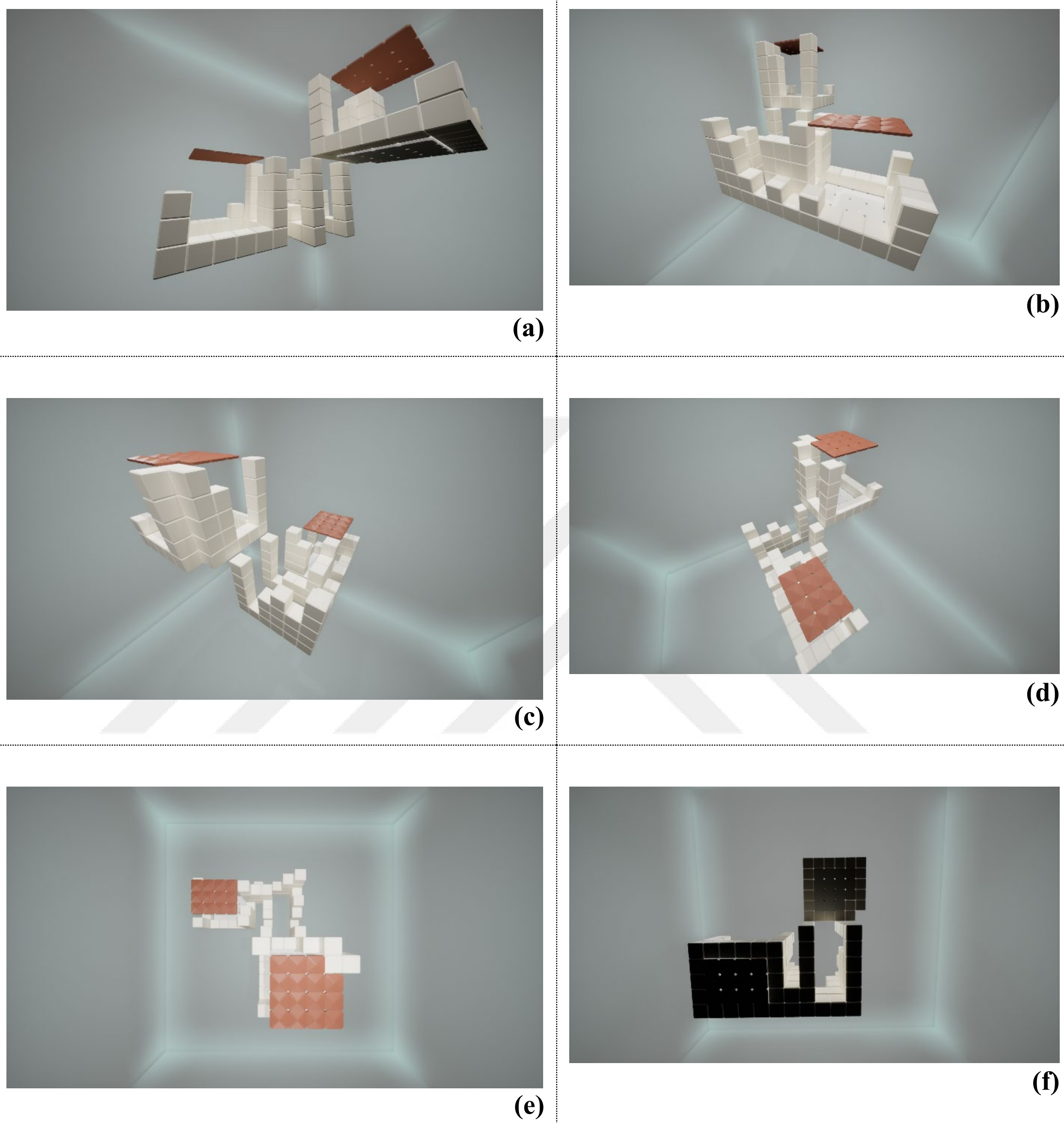


Figure A.16 : Images from test scene 8-P (Play Mode). (a), (b), (c), (d): Perspective view of the scene. (e): Top view, (f): Bottom view.

APPENDIX Q: Test Scene 9-B (Build Mode)

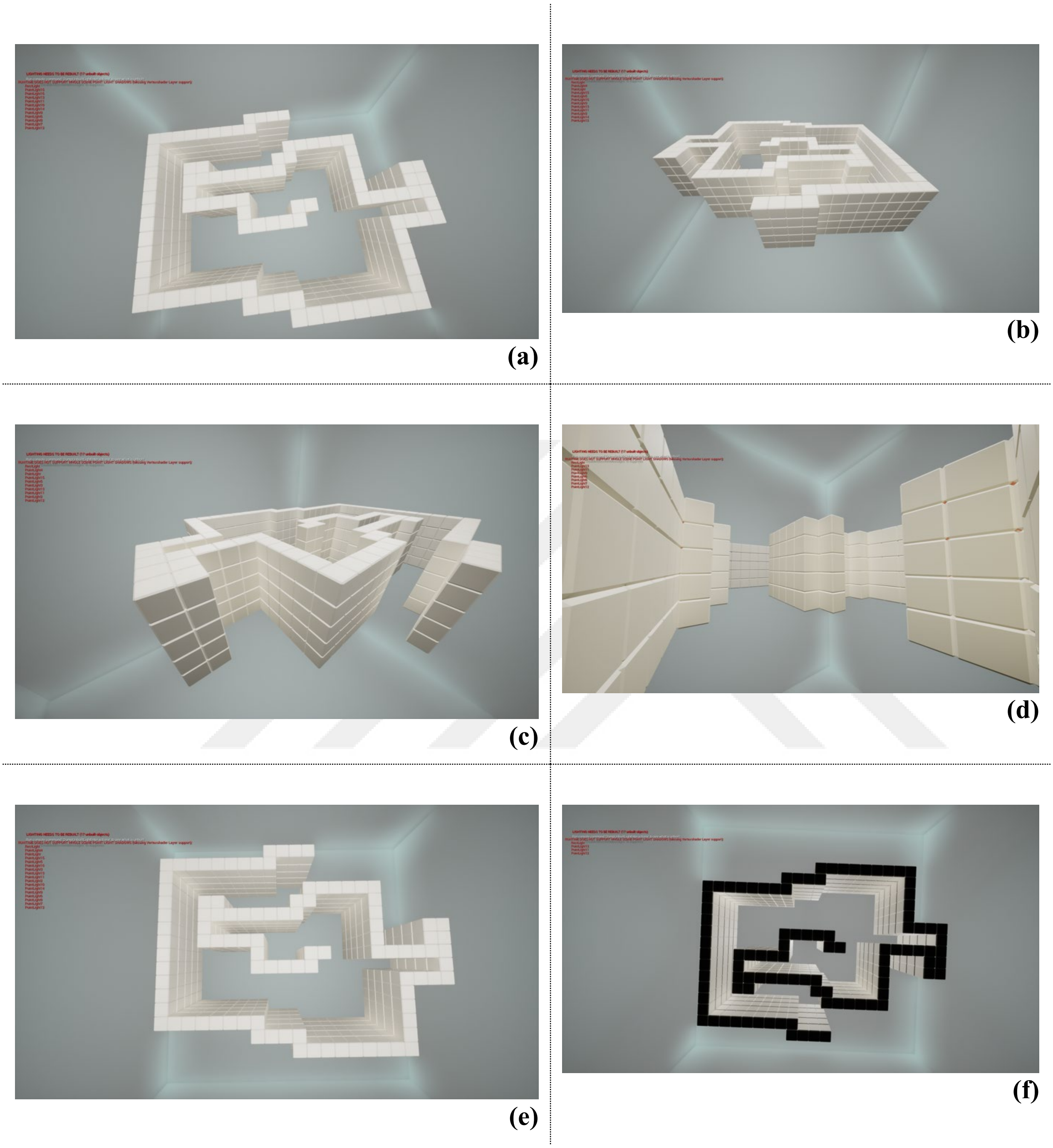


Figure A.17 : Images from test scene 9-B (Build Mode). (a), (b), (c), (d): Perspective view of the scene. (e): Top view, (f):Bottom view.

APPENDIX R: Test Scene 9-P (Play Mode)

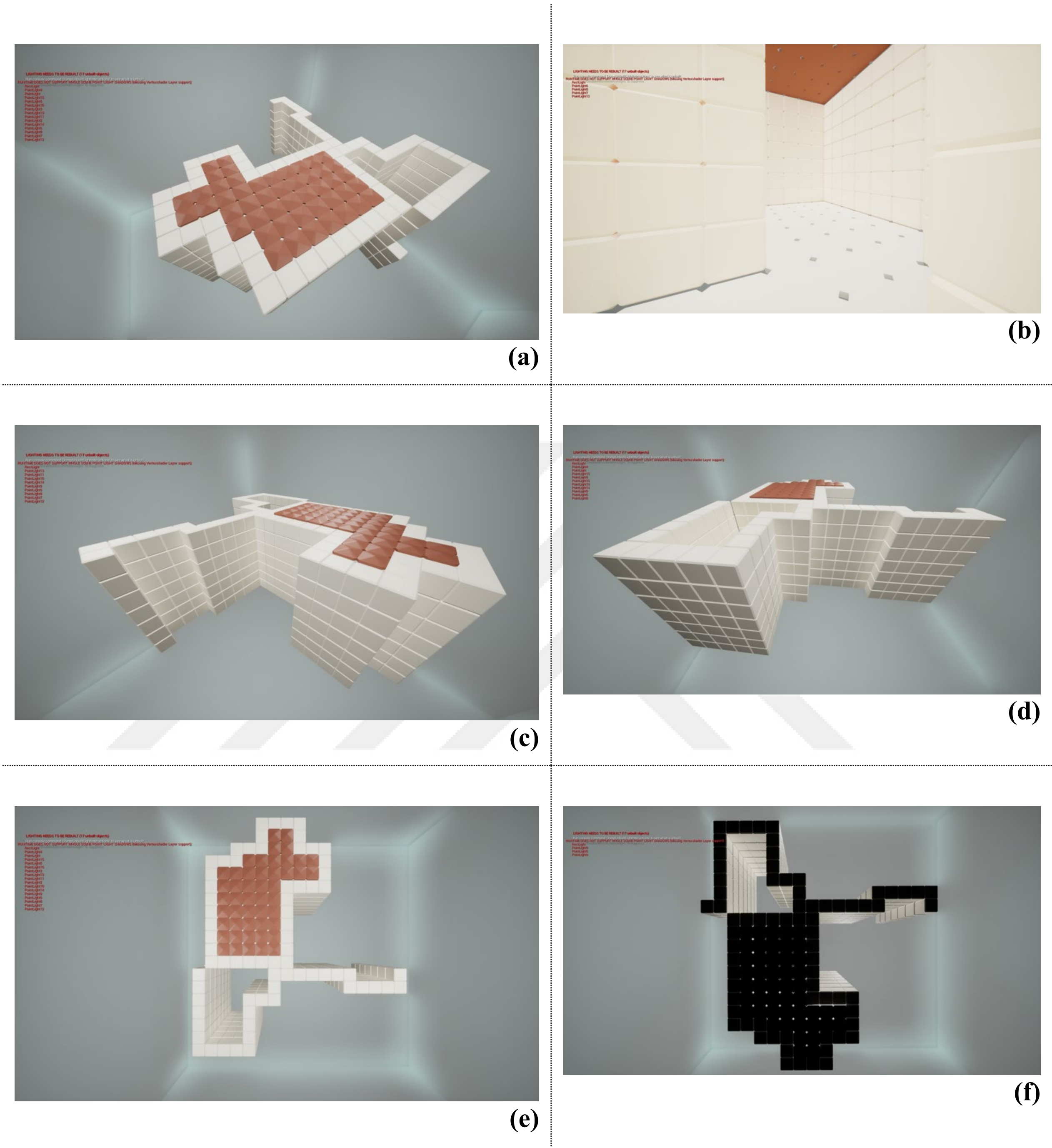


Figure A.18 : Images from test scene 9-P (Play Mode). (a), (b), (c), (d): Perspective view of the scene. (e): Top view, (f): Bottom view.

APPENDIX S: Test Scene 10-B (Build Mode)

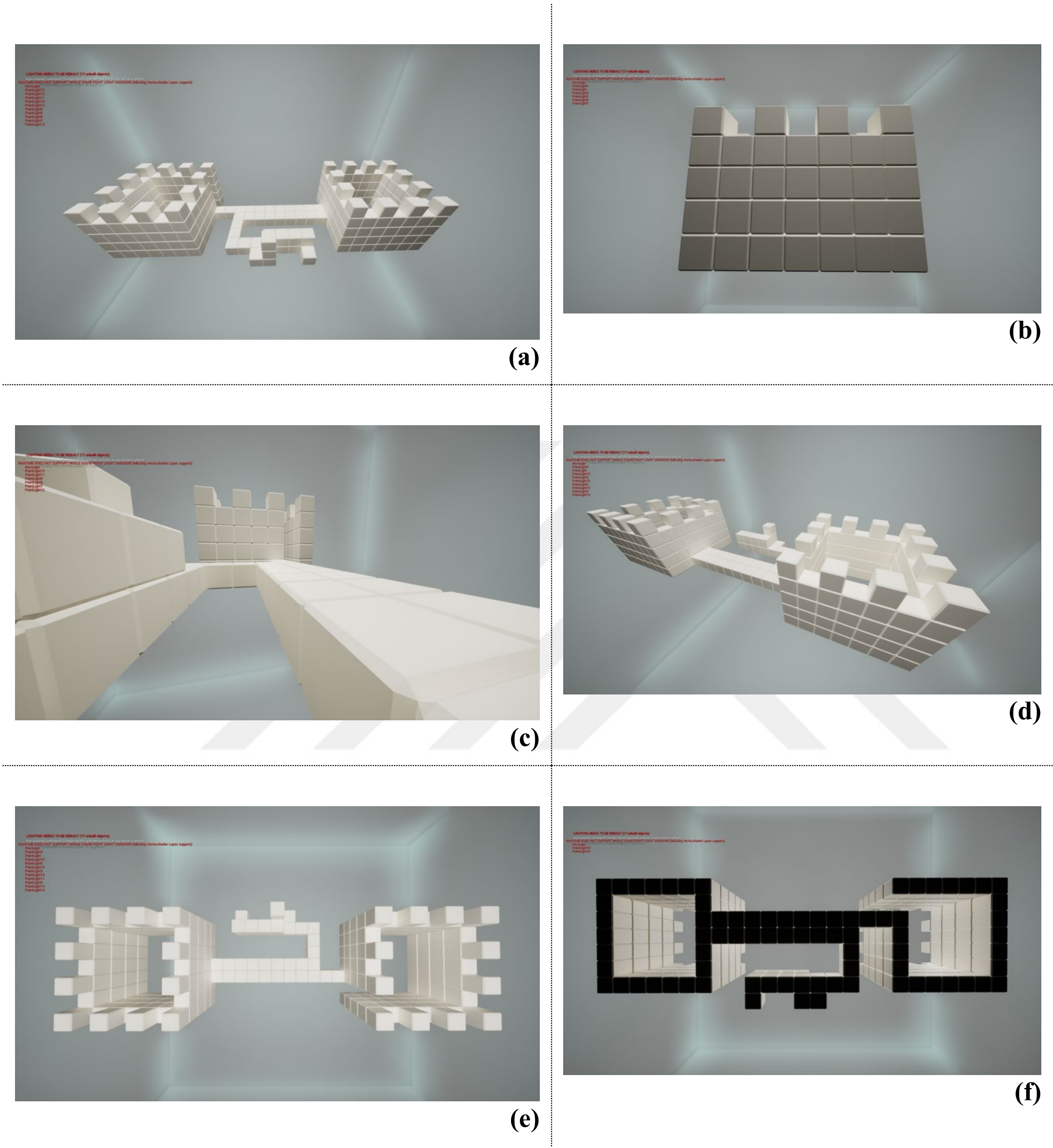


Figure A.19 : Images from test scene 10-B (Build Mode). (a), (b), (c), (d): Perspective view of the scene. (e): Top view, (f):Bottom view.

APPENDIX T: Test Scene 10-P (Play Mode)

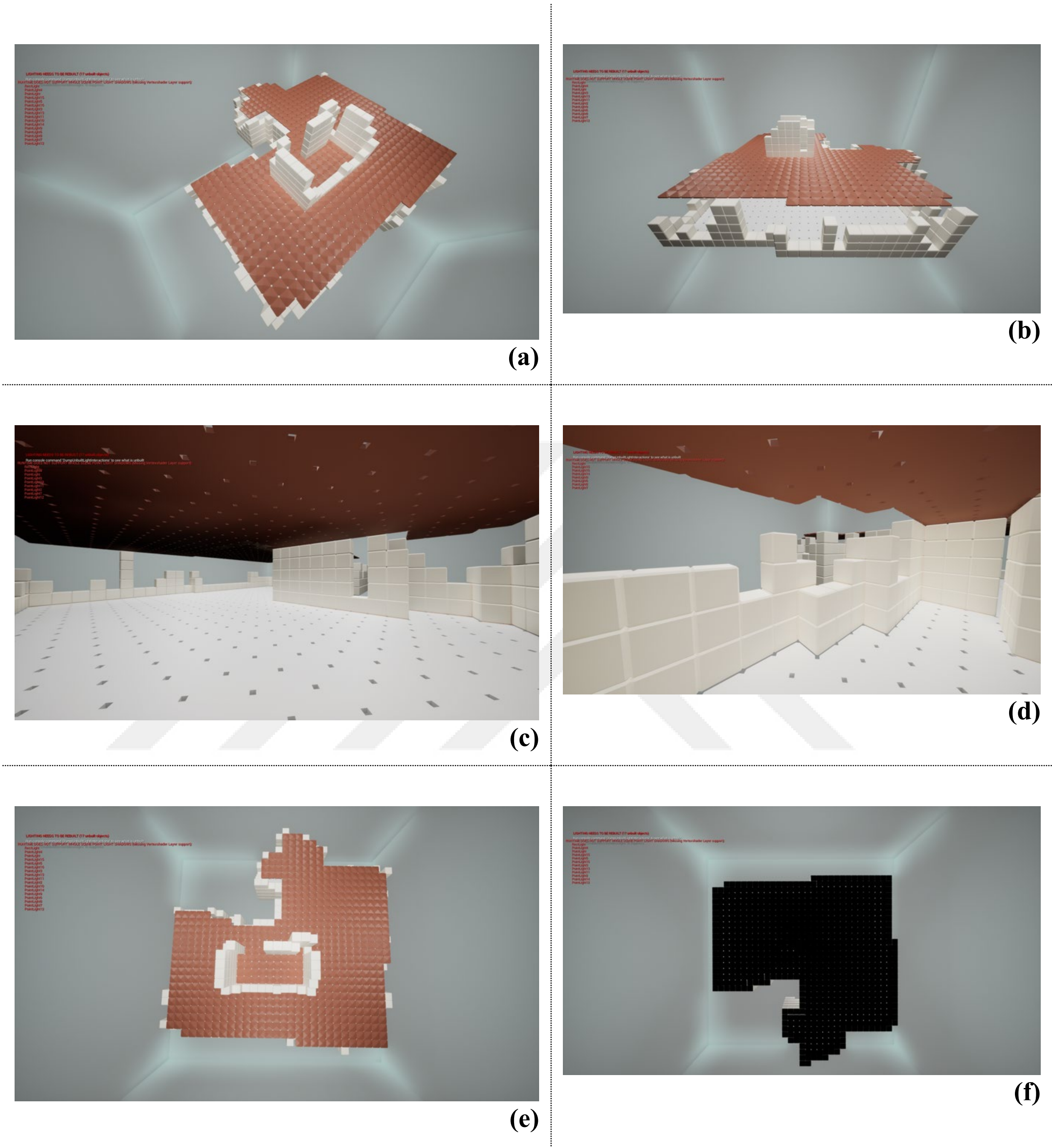


Figure A.20 : Images from test scene 10-P (Play Mode). (a), (b), (c), (d): Perspective view of the scene. (e): Top view, (f): Bottom view.

APPENDIX U: Test Scene 11-B (Build Mode)

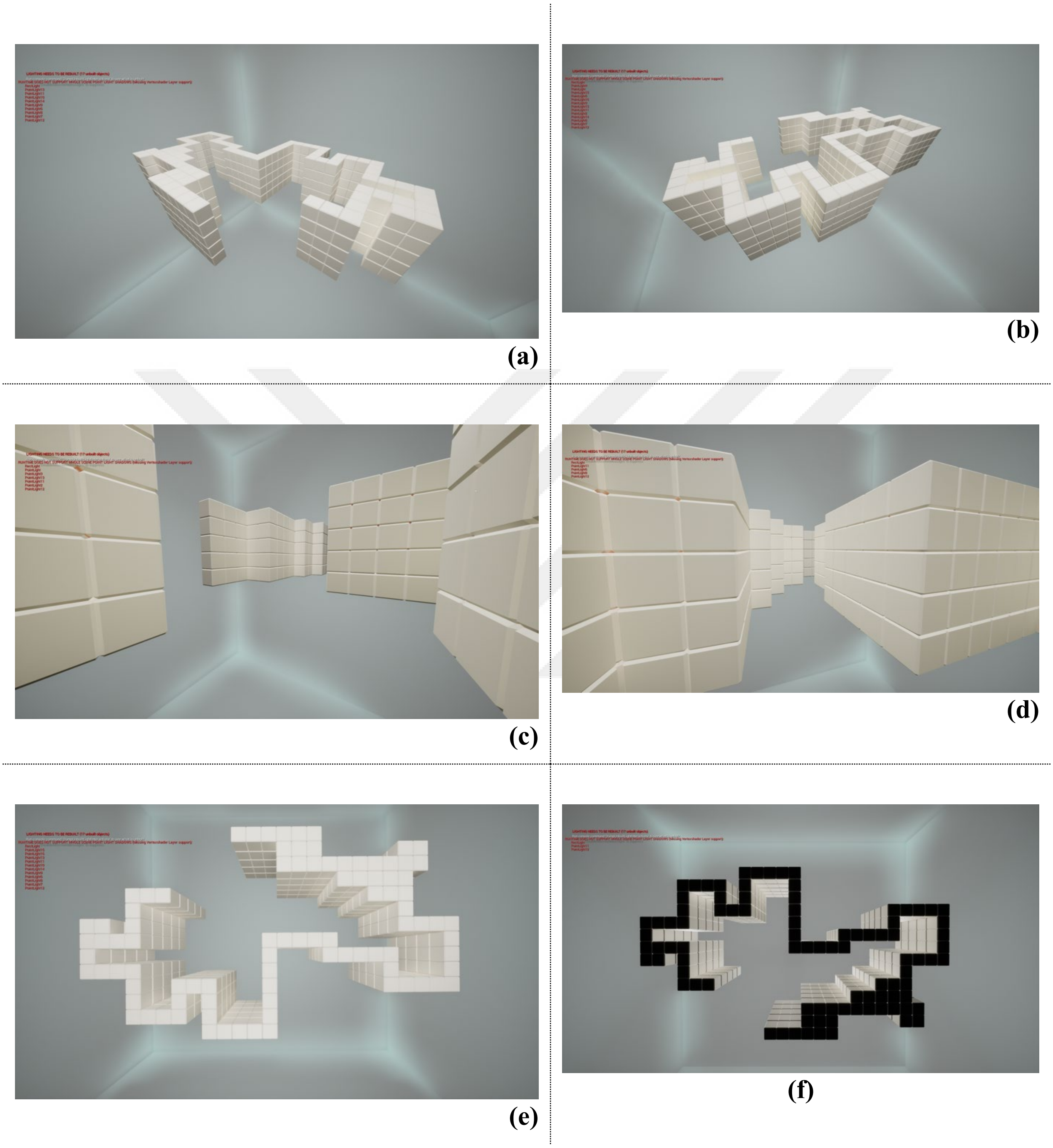


Figure A.21 : Images from test scene 11-B (Build Mode). (a), (b), (c), (d): Perspective view of the scene. (e): Top view, (f):Bottom view.

APPENDIX V: Test Scene 11-P (Play Mode)

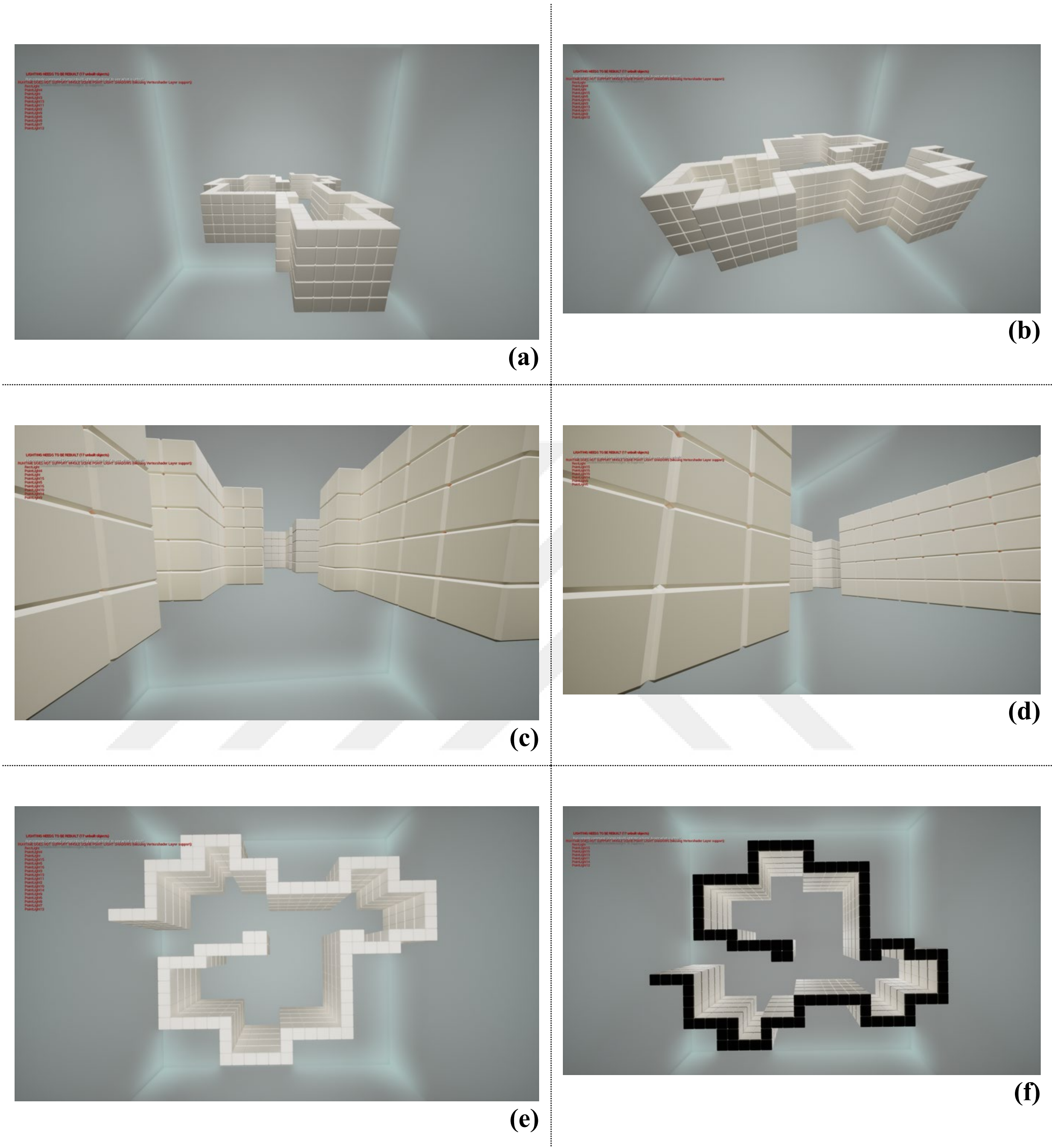


Figure A.22 : Images from test scene 11-P (Play Mode). (a), (b), (c), (d): Perspective view of the scene. (e): Top view, (f): Bottom view.

APPENDIX W: Test Scene 12-B (Build Mode)

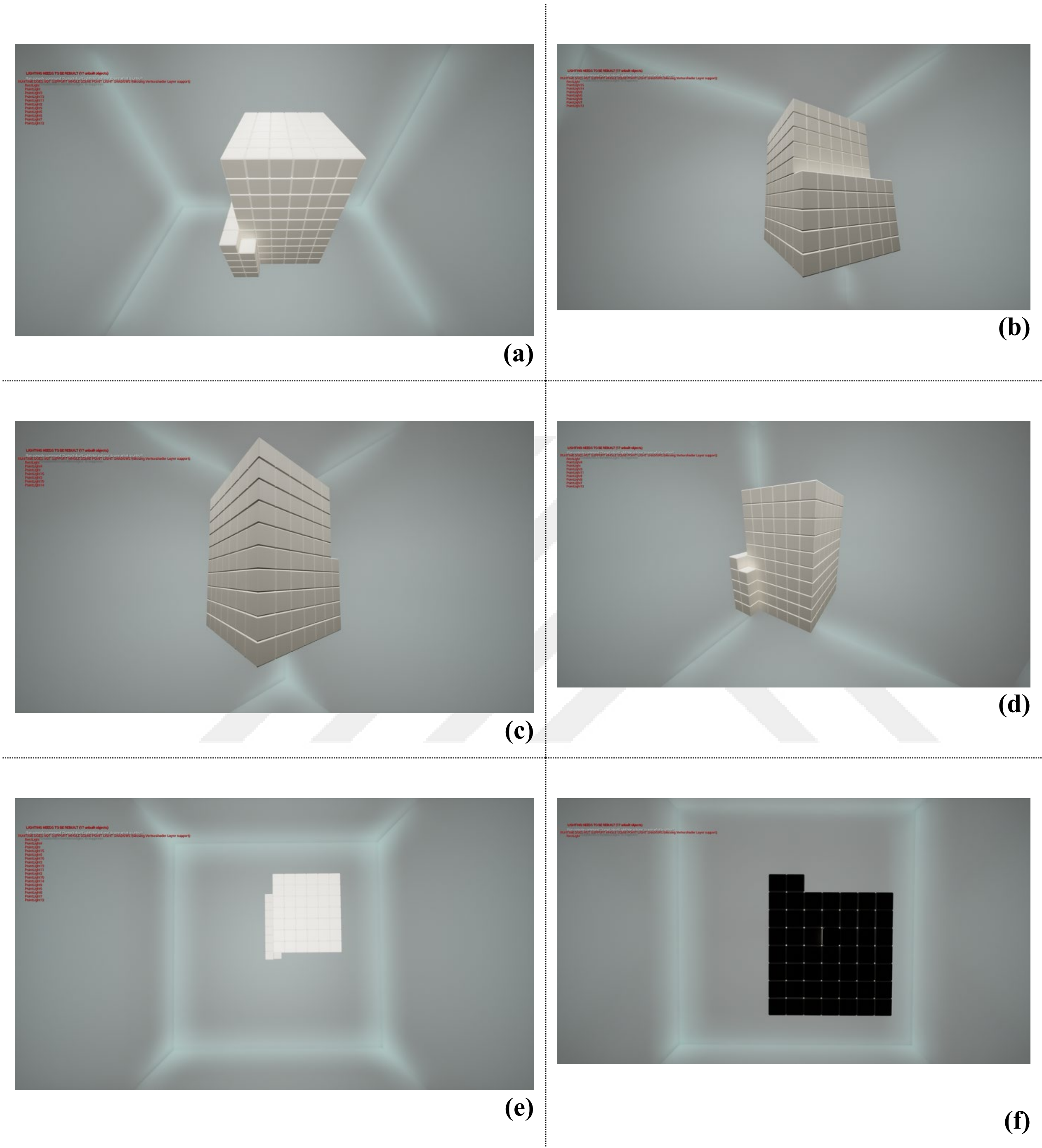


Figure A.23 : Images from test scene 12-B (Build Mode). (a), (b), (c), (d): Perspective view of the scene. (e): Top view, (f):Bottom view.

APPENDIX X: Test Scene 12-P (Play Mode)

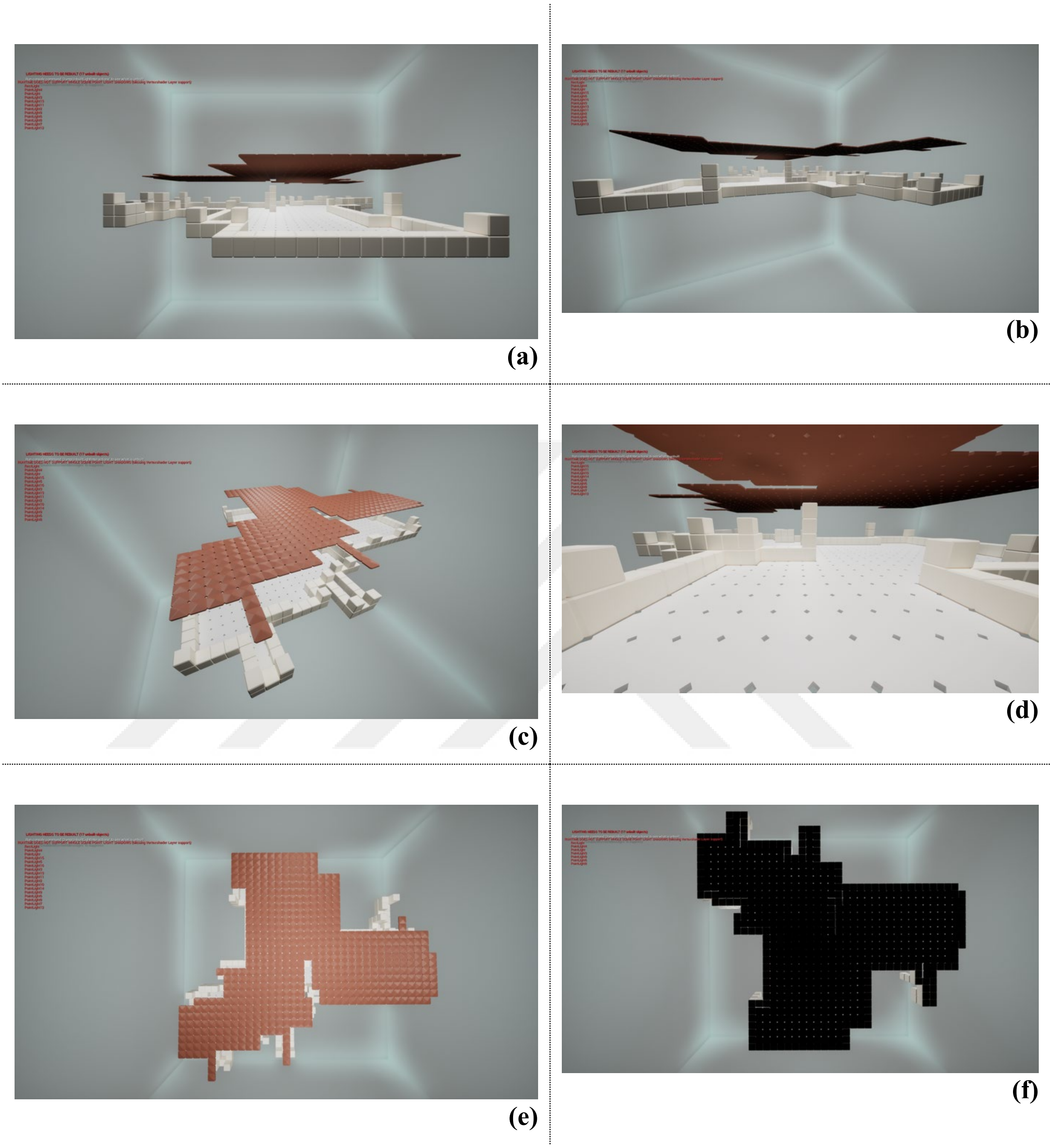


Figure A.24 : Images from test scene 12-P (Play Mode). (a), (b), (c), (d): Perspective view of the scene. (e): Top view, (f): Bottom view.

APPENDIX Y: Test Scene 13-B (Build Mode)

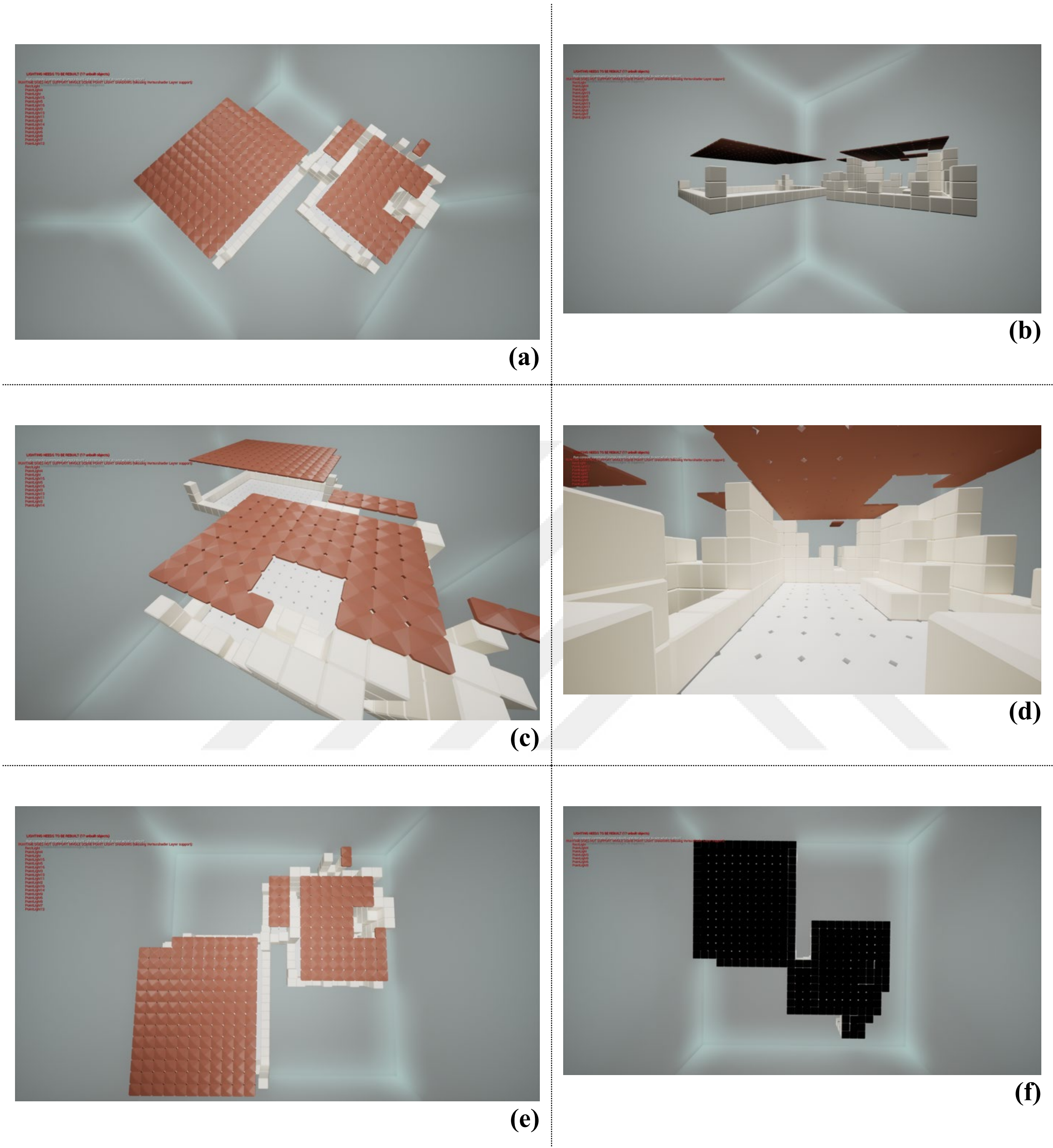


Figure A.25 : Images from test scene 13-B (Build Mode). (a), (b), (c), (d): Perspective view of the scene. (e): Top view, (f):Bottom view.

APPENDIX Z: Test Scene 13-P (Play Mode)

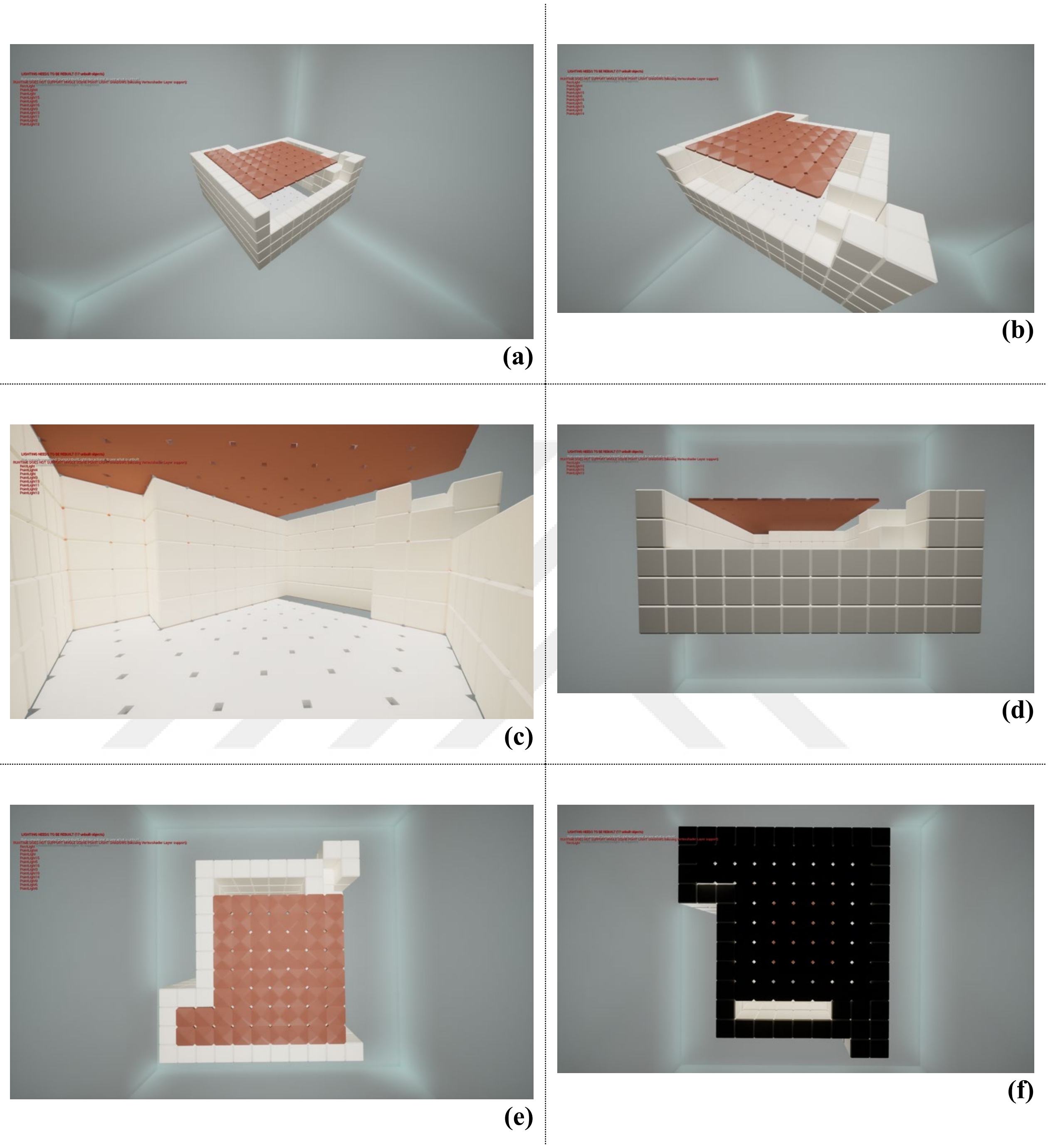
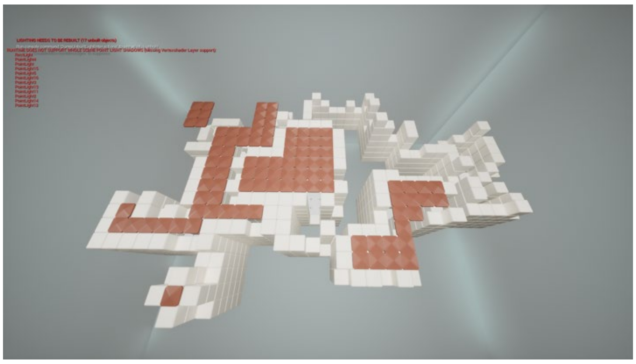
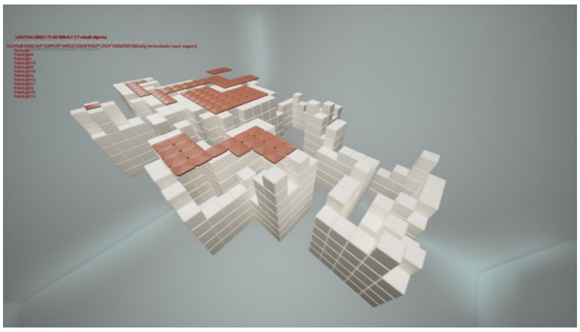


Figure A.26 : Images from test scene 13-P (Play Mode). (a), (b), (c), (d): Perspective view of the scene. (e): Top view, (f): Bottom view.

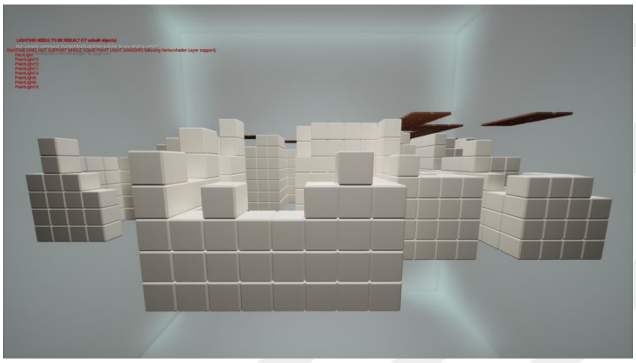
APPENDIX 1-A: Test Scene 14-B (Build Mode)



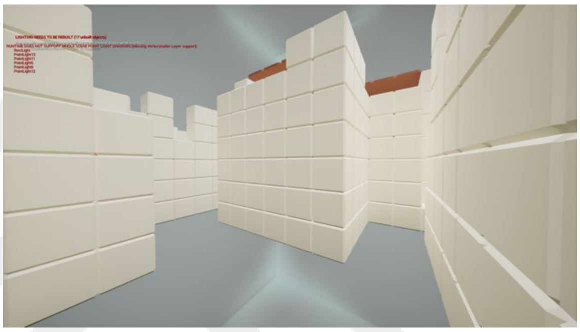
(a)



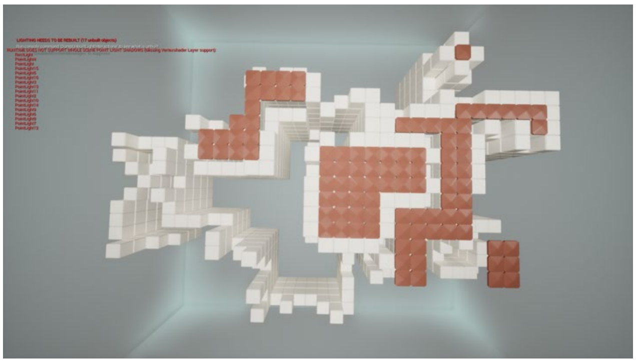
(b)



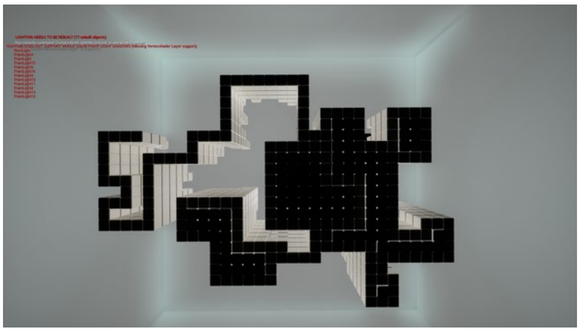
(c)



(d)



(e)



(f)

Figure A.27 : Images from test scene 14-B (Build Mode). (a), (b), (c), (d): Perspective view of the scene. (e): Top view, (f):Bottom view.

APPENDIX 1-B: Test Scene 14-P (Play Mode)

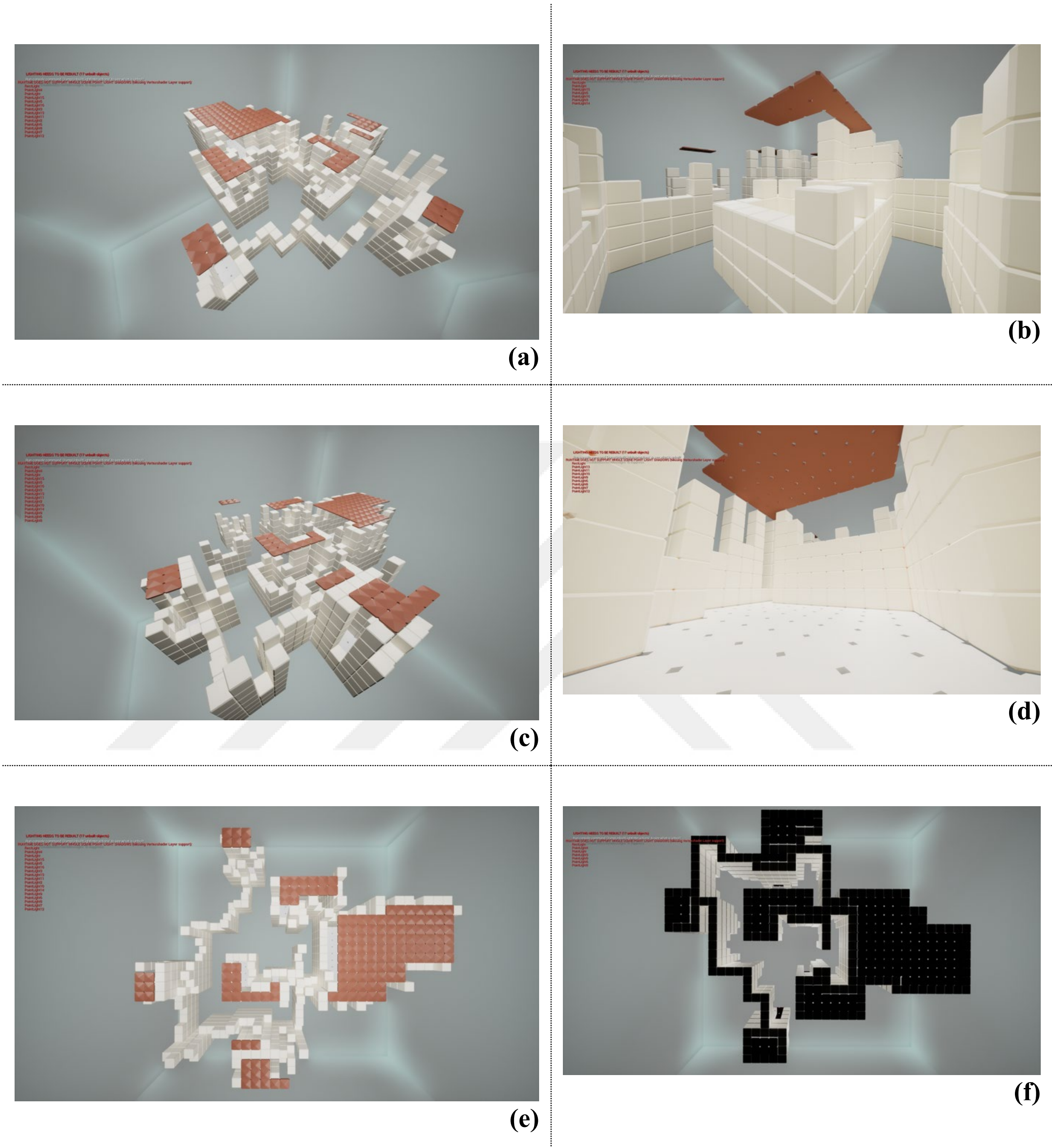


Figure A.28 : Images from test scene 14-P (Play Mode). (a), (b), (c), (d): Perspective view of the scene. (e): Top view, (f): Bottom view.

APPENDIX 1-C: Test Scene 15-B (Build Mode)

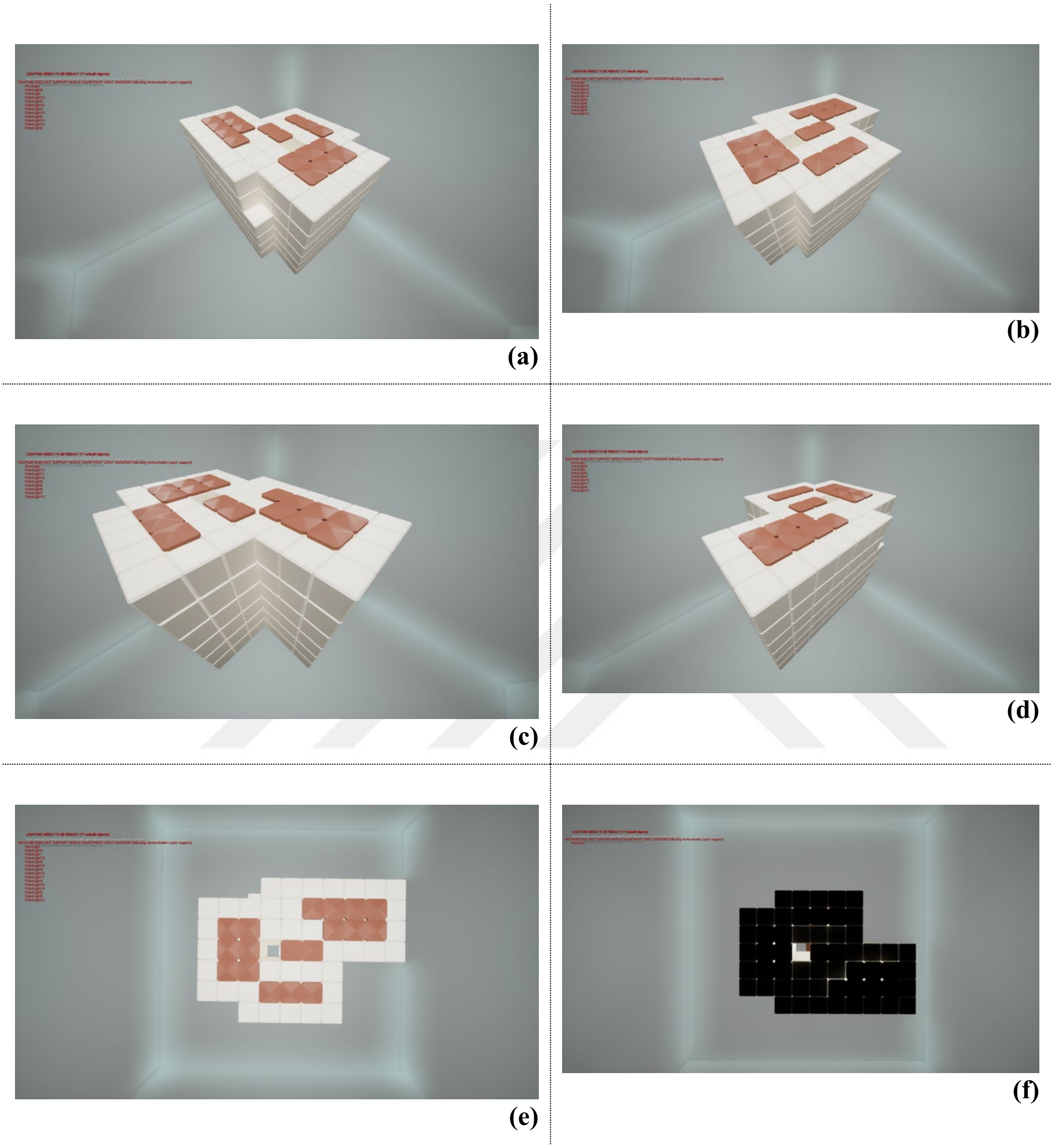


Figure A.29 : Images from test scene 15-B (Build Mode). (a), (b), (c), (d): Perspective view of the scene. (e): Top view, (f):Bottom view.

APPENDIX 1-D: Test Scene 15-P (Play Mode)

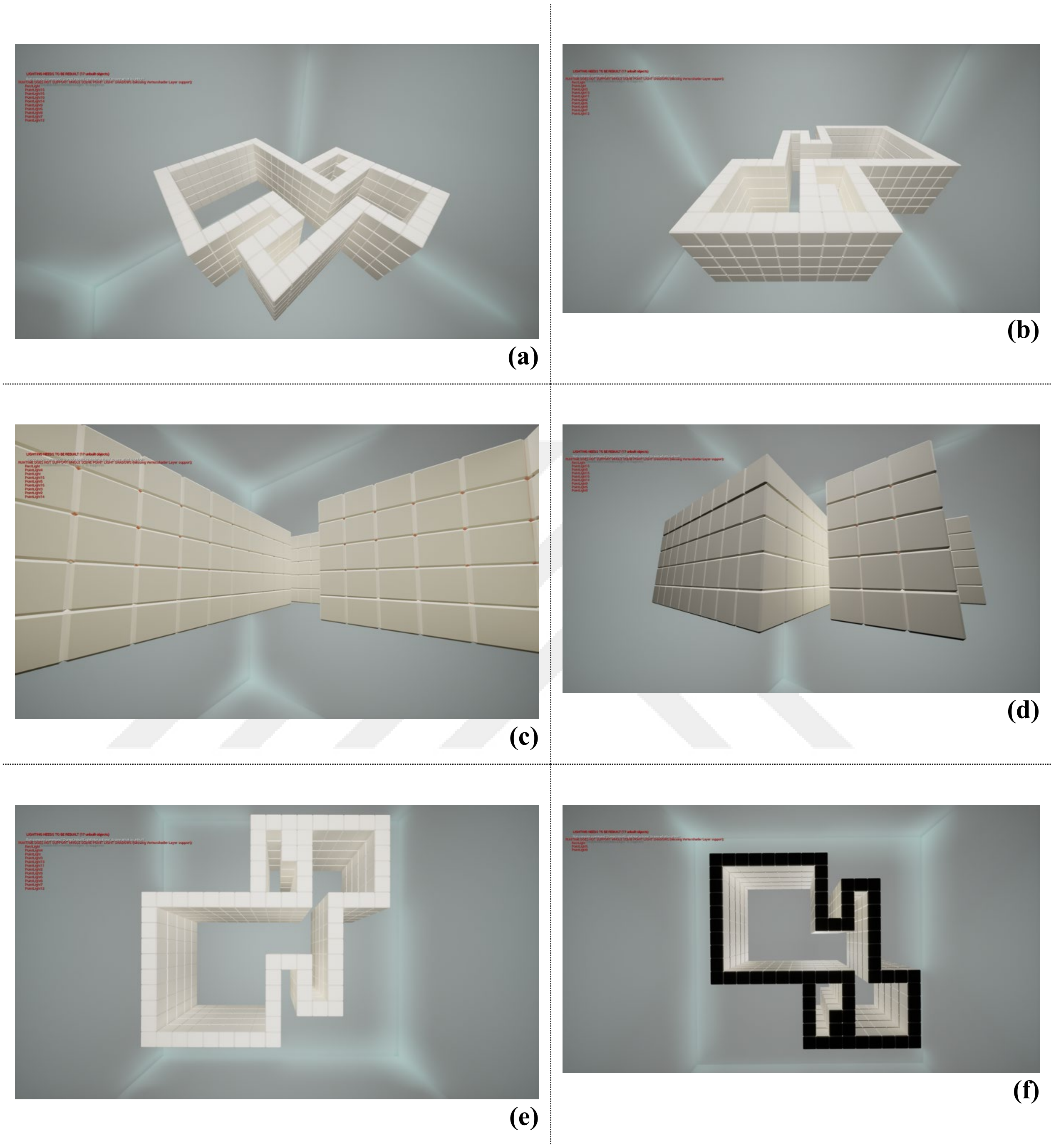


Figure A.30 : Images from test scene 15-P (Play Mode). (a), (b), (c), (d): Perspective view of the scene. (e): Top view, (f): Bottom view.

APPENDIX 1-E: Test Scene 16-B (Build Mode)

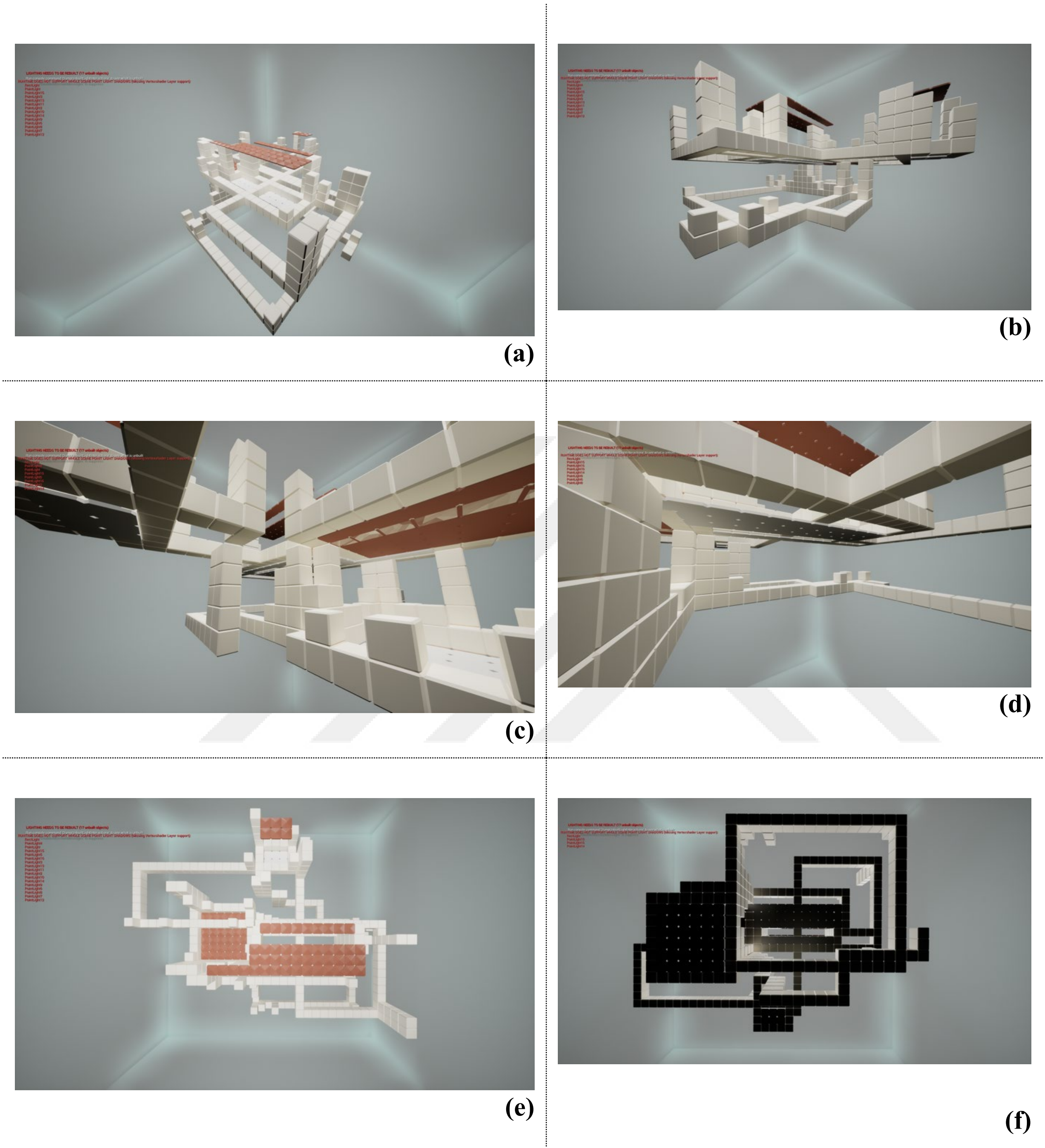


Figure A.31 : Images from test scene 16-B (Build Mode). (a), (b), (c), (d): Perspective view of the scene. (e): Top view, (f):Bottom view.

APPENDIX 1-F: Test Scene 16-P (Play Mode)

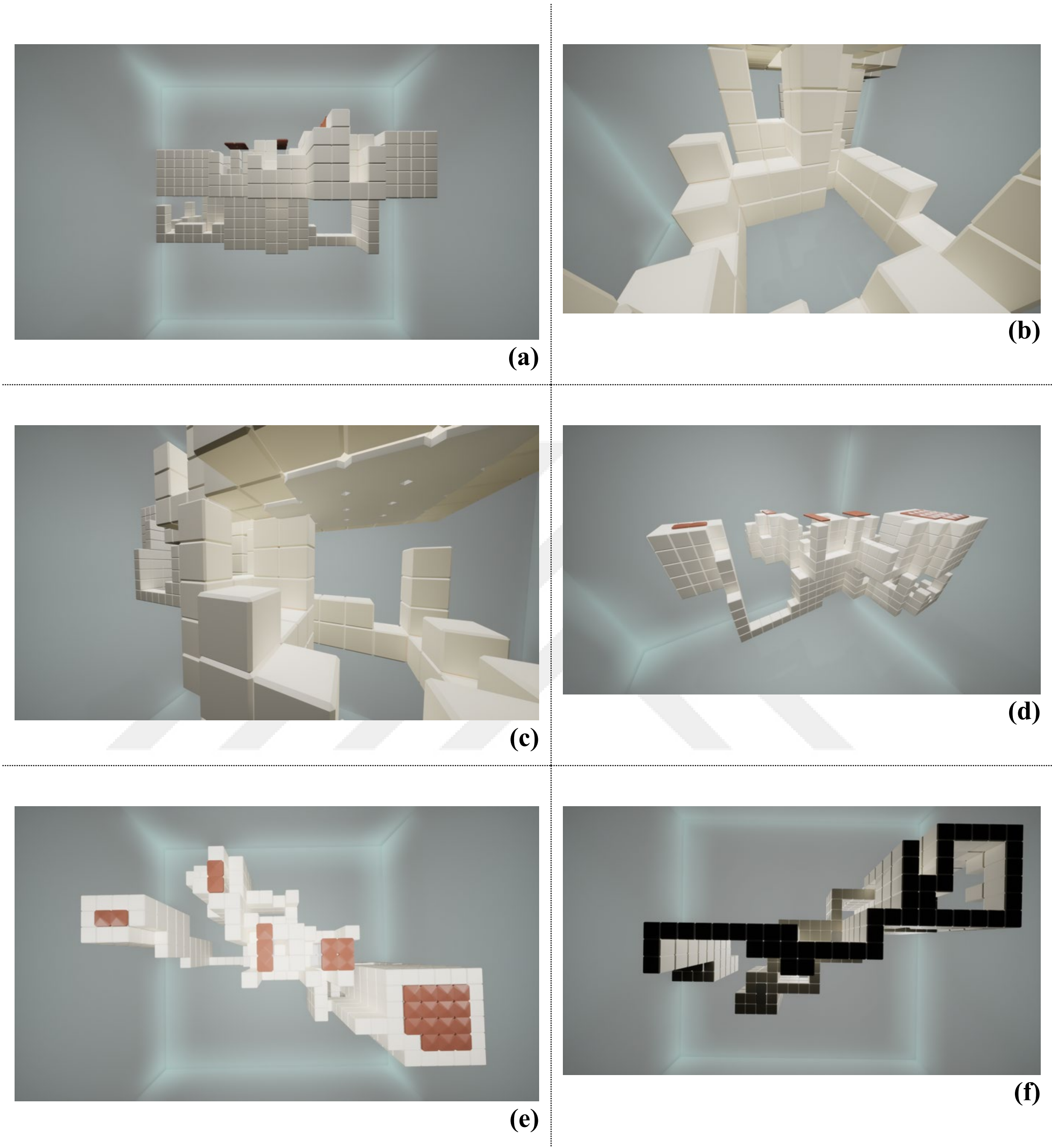


Figure A.32 : Images from test scene 16-P (Play Mode). (a), (b), (c), (d): Perspective view of the scene. (e): Top view, (f): Bottom view.

APPENDIX 1-G: Test Scene 17-B (Build Mode)

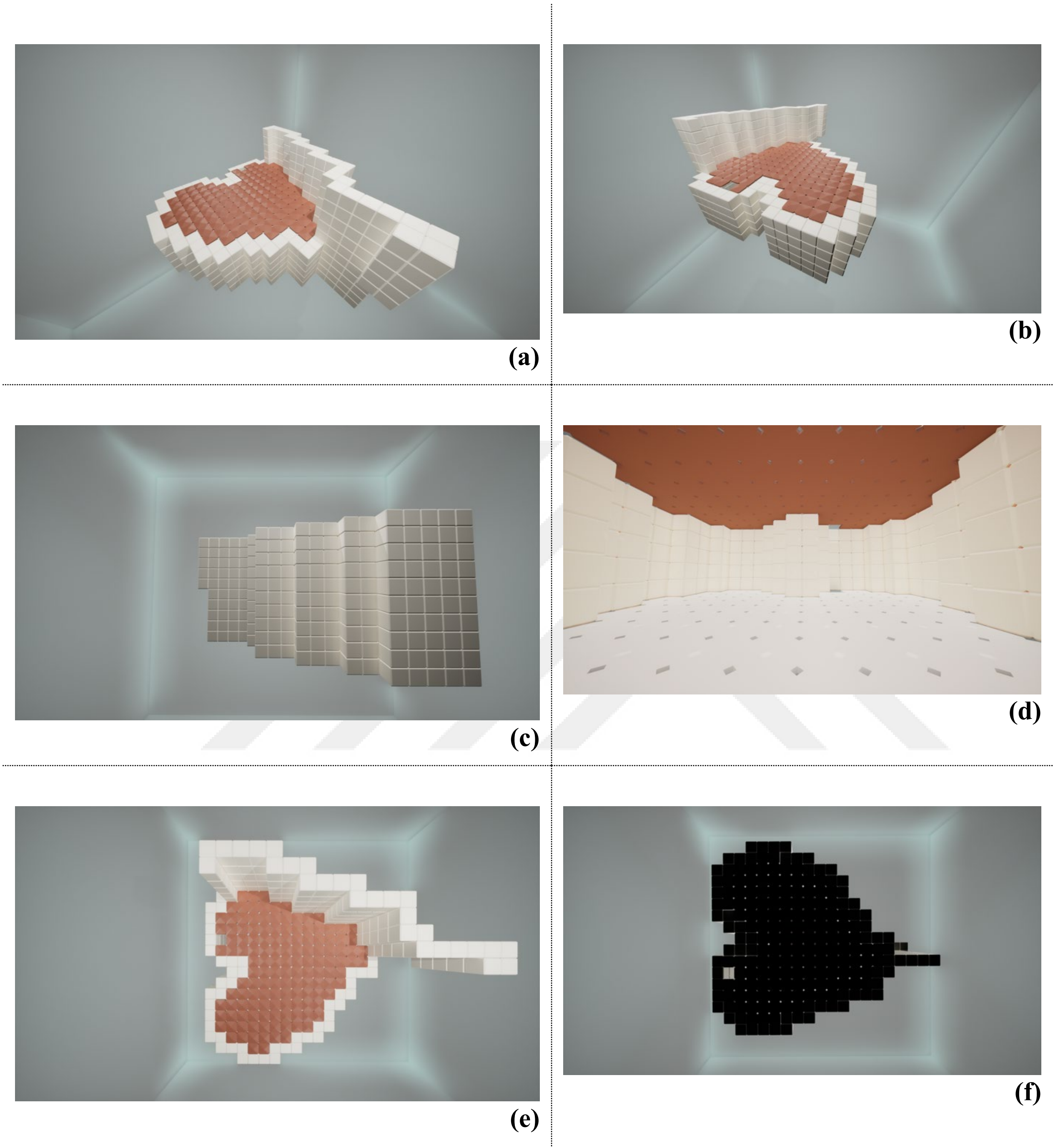


Figure A.33 : Images from test scene 17-B (Build Mode). (a), (b), (c), (d): Perspective view of the scene. (e): Top view, (f):Bottom view.

APPENDIX 1-H: Test Scene 17-P (Play Mode)

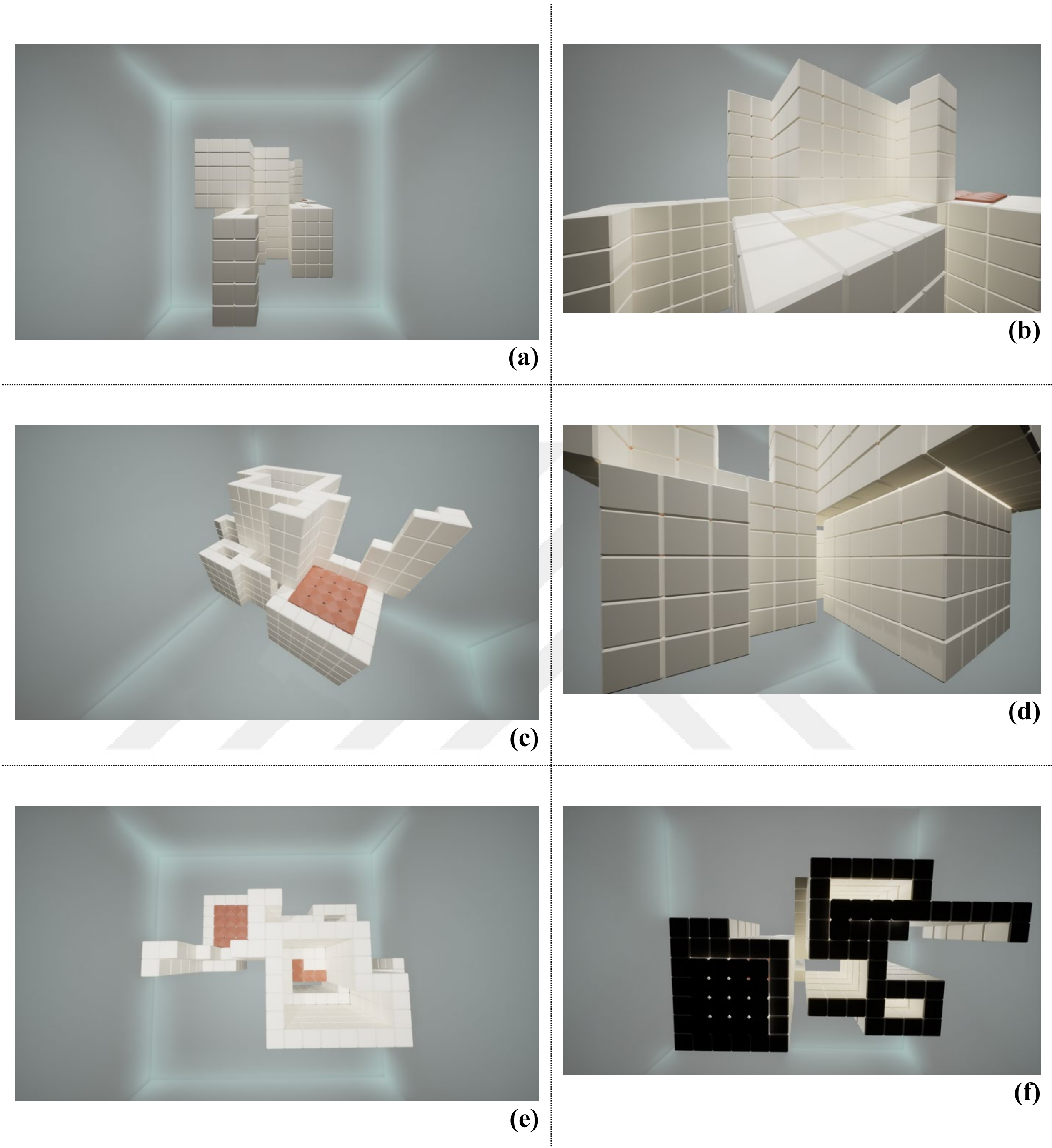


Figure A.34 : Images from test scene 17-P (Play Mode). (a), (b), (c), (d): Perspective view of the scene. (e): Top view, (f): Bottom view.

APPENDIX 1-I: Test Scene 18-B (Build Mode)

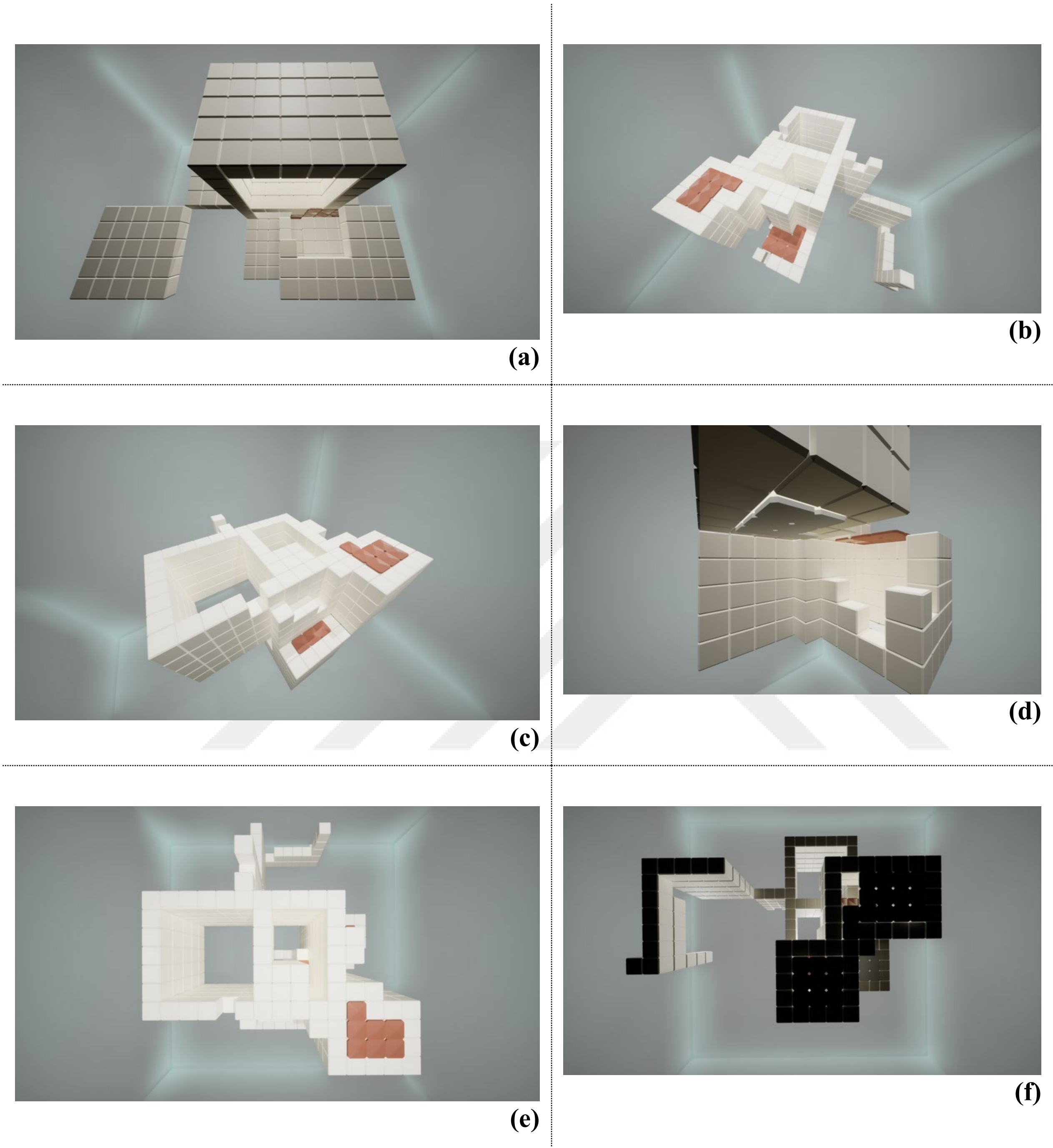


Figure A.35 : Images from test scene 18-B (Build Mode). (a), (b), (c), (d): Perspective view of the scene. (e): Top view, (f):Bottom view.

APPENDIX 1-J: Test Scene 18-P (Play Mode)

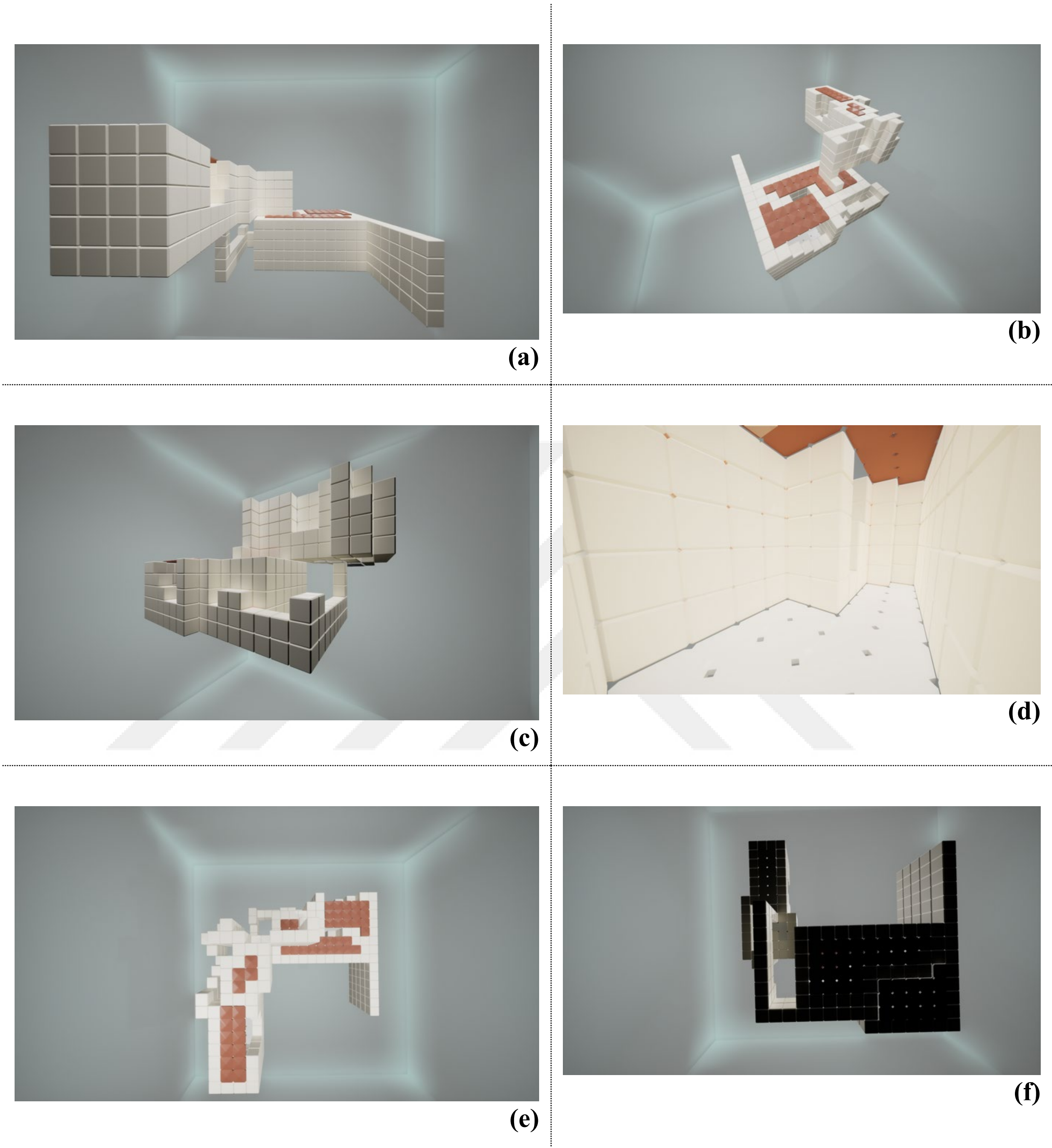


Figure A.36 : Images from test scene 18-P (Play Mode). (a), (b), (c), (d): Perspective view of the scene. (e): Top view, (f): Bottom view.

APPENDIX 1-K: Test Scene 19-B (Build Mode)

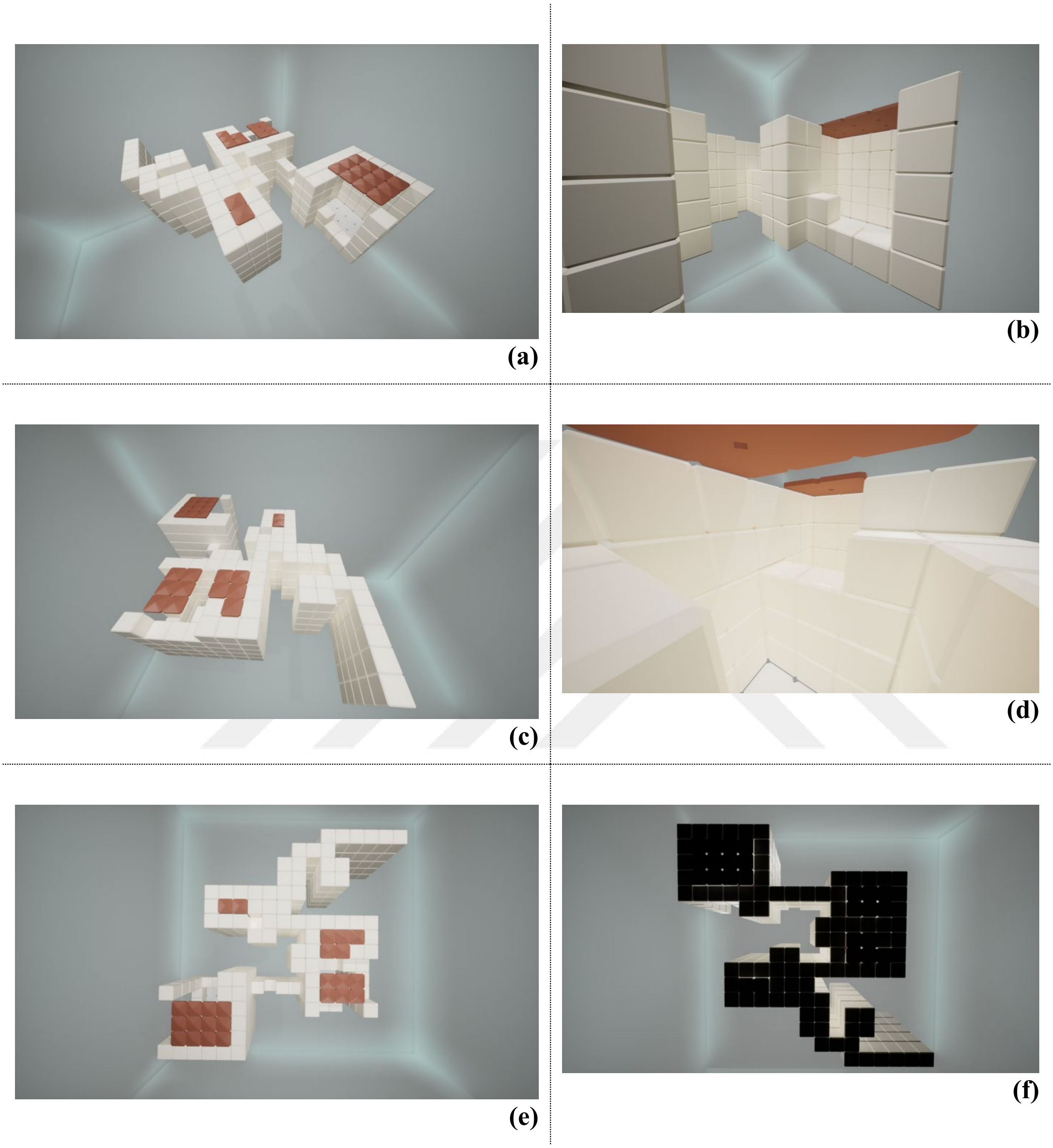
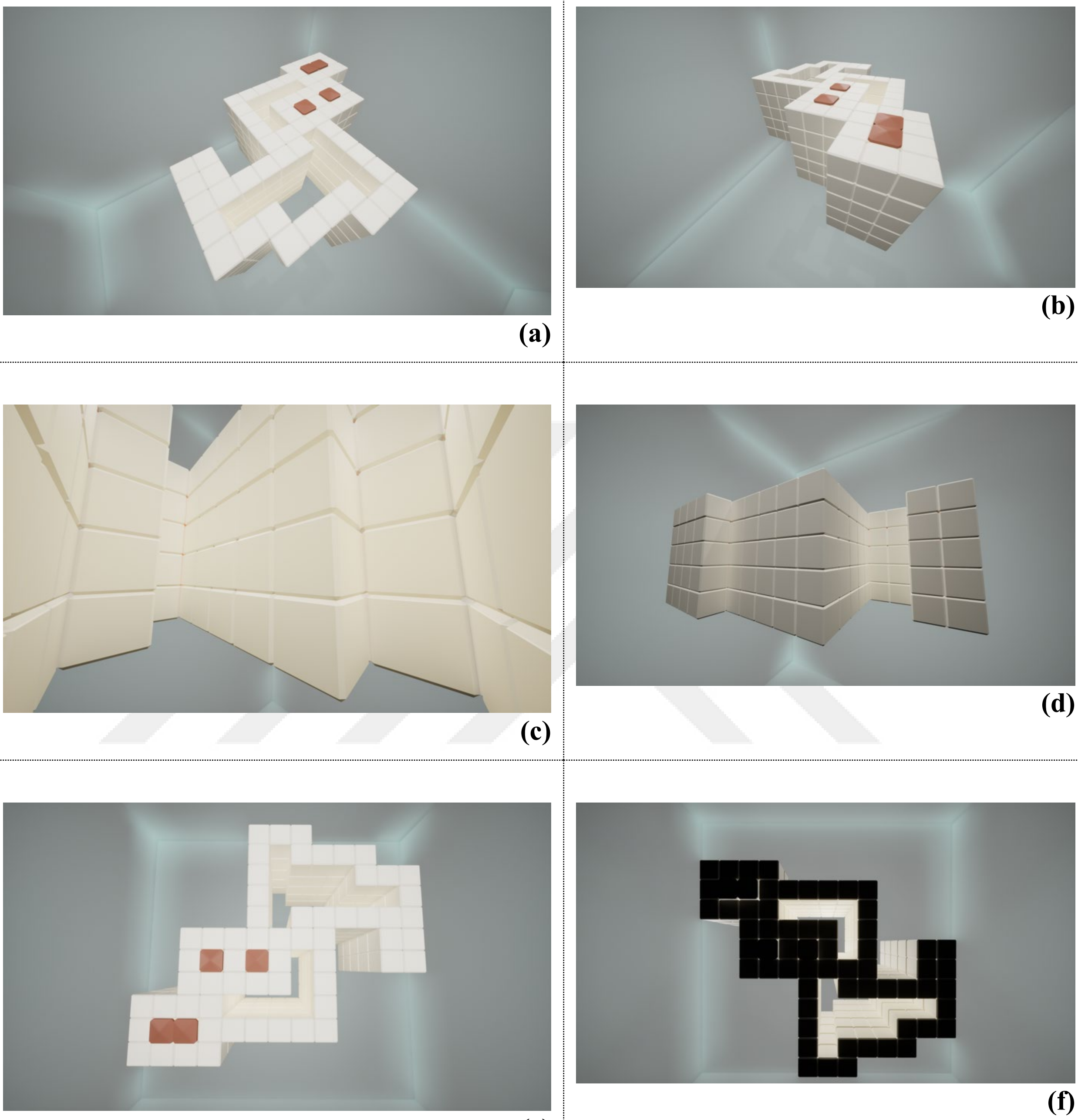


Figure A.37 : Images from test scene 19-B (Build Mode). (a), (b), (c), (d): Perspective view of the scene. (e): Top view, (f): Bottom view.

APPENDIX 1-L: Test Scene 19-P (Play Mode)



(a) (b) (c) (d) (e) (f)

Figure A.38 : Images from test scene 19-P (Play Mode). (a), (b), (c), (d): Perspective view of the scene. (e): Top view, (f): Bottom view.

APPENDIX 1-M: Test Scene 20-B (Build Mode)

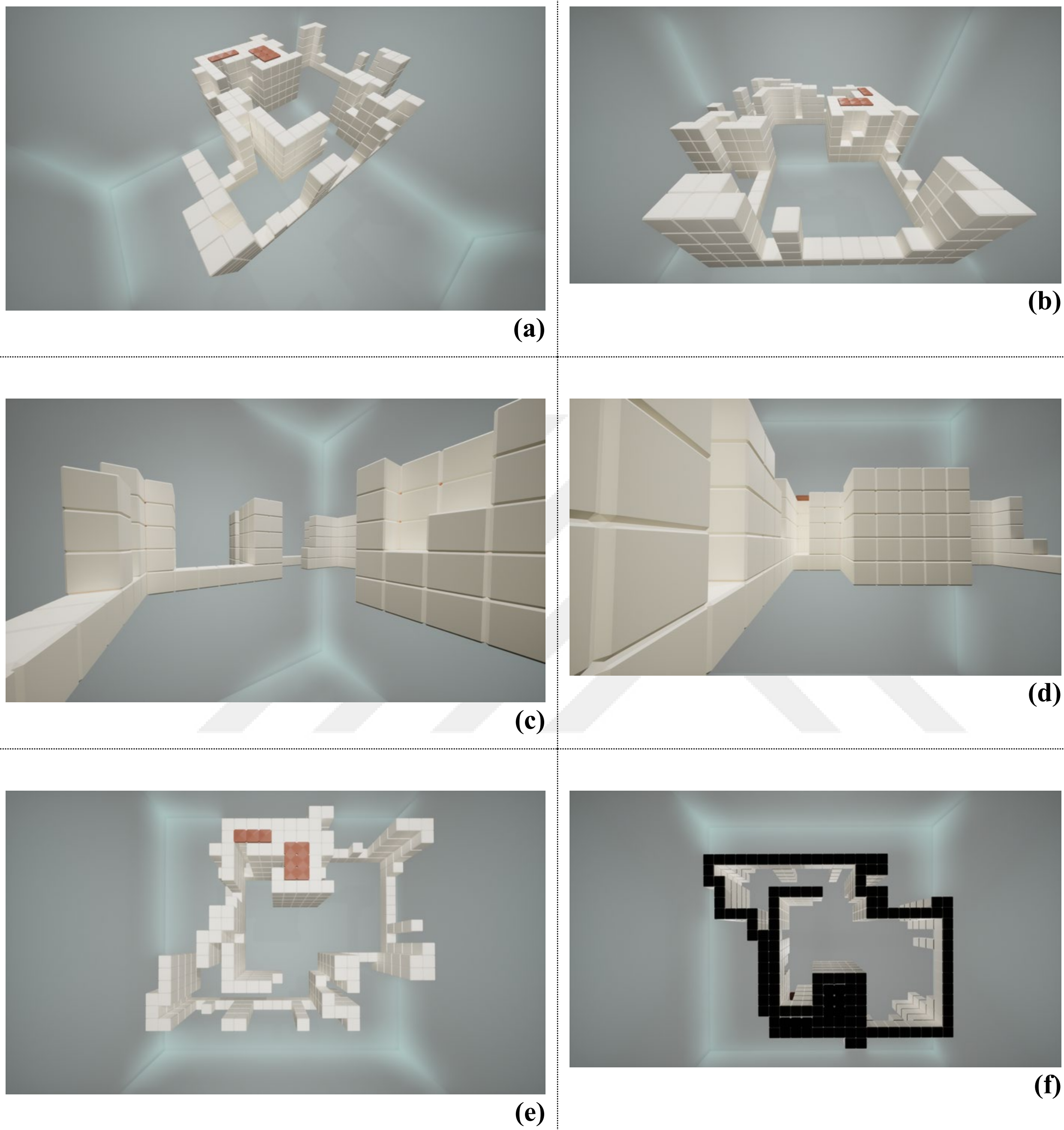


Figure A.39 : Images from test scene 19-B (Build Mode). (a), (b), (c), (d): Perspective view of the scene. (e): Top view, (f):Bottom view.

APPENDIX 1-N: Test Scene 20-P (Play Mode)

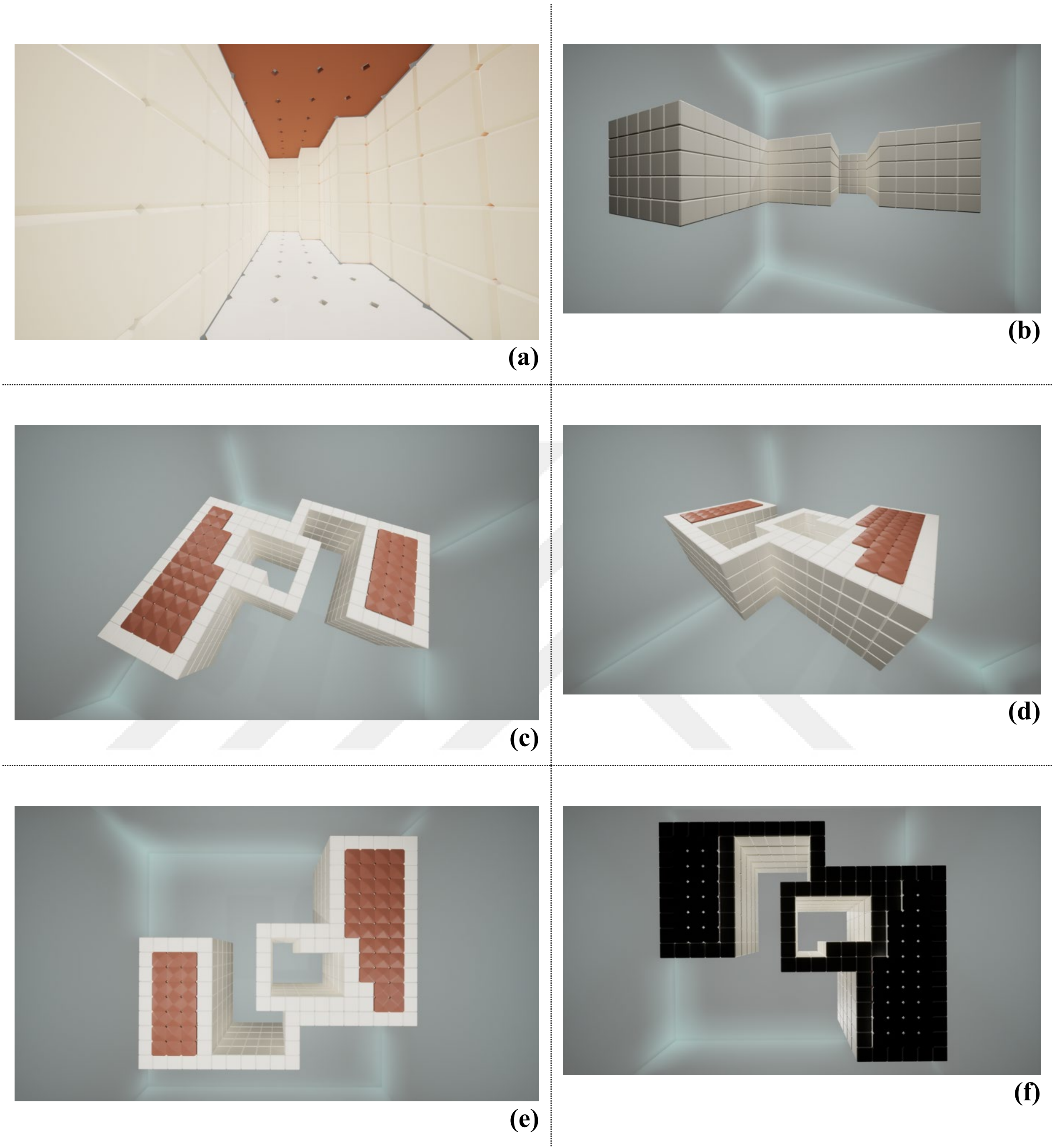


Figure A.40 : Images from test scene 20-P (Play Mode). (a), (b), (c), (d): Perspective view of the scene. (e): Top view, (f): Bottom view.

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