

**ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL**

**AN ENTROPY-BASED ANALYSIS APPROACH FOR 3D GAME  
ENVIRONMENTS UTILIZING PROXIMITY OF GAME ASSETS**



**M.Sc. THESIS**

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**Department of Game and Interaction Technologies**

**Game and Interaction Technologies Programme**

**JUNE 2023**



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**İSTANBUL TEKNİK ÜNİVERSİTESİ ★ LİSANSÜSTÜ EĞİTİM ENSTİTÜSÜ**

**3B OYUN MEKANLARI İÇİN OYUN VARLIKLARI ARASINDAKİ MESAFE  
ÜZERİNDEN ENTROPİ TABANLI BİR ANALİZ YAKLAŞIMI**

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Efay Izel Tan, a M.Sc. student of ITU Graduate School student ID 529201005 successfully defended the thesis/dissertation entitled “AN ENTROPY-BASED ANALYSIS APPROACH FOR 3D GAME ENVIRONMENTS UTILIZING PROXIMITY OF GAME ASSETS”, which she prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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*To my parents,*



## FOREWORD

First of all, I would like to express my gratitude to my thesis advisor, Assoc. Prof. Dr. Sema Alaçam has been an inspiration to me since 2015. She has always supported me, provided motivation, and served as a role model with her enthusiasm for design, creation, research, and dedication. I am truly thankful for everything. I would also like to extend my gratitude to my thesis co-advisor, Dr. Hüseyin Kutay Tınç, for his unwavering support and assistance. In addition to his valuable contributions to my thesis work, he has taught me a great deal throughout my master's studies and has been supportive in every aspect.

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June 2023

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Architect



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## ABBREVIATIONS

|             |                                         |
|-------------|-----------------------------------------|
| <b>3D</b>   | : Three Dimensional                     |
| <b>3B</b>   | : 3 Boyutlu                             |
| <b>RPG</b>  | : Role-playing Game                     |
| <b>TPS</b>  | : Third-person Shooter                  |
| <b>RTP</b>  | : Relationship Type Parameters          |
| <b>OOPR</b> | : Overall Object-Proximity Relationship |
| <b>UORP</b> | : Unique Object-Proximity Relationship  |
| <b>VR</b>   | : Virtual Reality                       |
| <b>XR</b>   | : Extended Reality                      |





## SYMBOLS

**p** : Entropy Calculation





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# **AN ENTROPY-BASED ANALYSIS APPROACH FOR 3D GAME ENVIRONMENTS UTILIZING PROXIMITY OF GAME ASSETS**

## **SUMMARY**

The main goal of this study is to systematically measure the 3D compositions of the virtual environment elements through the entropy method. Analyzing the relationship of the elements in the virtual environment in 3D, it is aimed to approach the virtual space design process with an objective point of view and capture the transition process of space creation to the virtual environment.

While there are many publications on the aesthetic relationship of entropy to 2D image examination and several game analyses, this study differentiates itself from others by focusing on 3D decomposition, entropy measurement, and 3D composition analysis of virtual space elements.

Games environments are selected for measuring as virtual space type. From 11 science fiction and fantasy games (God of War 4, Aion Tower of Eternity, Ghost Of Tsushima, Journey, Star Wars Jedi: Fallen Order, Elden Ring, Control, Destiny 2, Doom, Mass Effect 2, Titanfall 2), 22 scenes were chosen for analysis. Action-adventure or RPG and TPS game types, which are considered successful by getting high scores from the players, were selected, in general. Since the composition of the virtual world rather than the physical world is wanted to be investigated, games in futuristic, sci-fi fiction are included instead of games that copy reality.

This research selected passive 3D game assets called pictorial space as the primary elements. The 3D game assets present in the selected scenes were employed as the source objects. These source objects were categorized according to their similarity or dissimilarity. A letter-based labeling system was used to identify the source objects, with objects of the same type assigned the same letter. The Excel table was utilized to organize and process the source object numbers and characteristics from all the games.

2D screenshots were taken from the selected games, and a 3D representation was provided by modeling and moving 3D cube models in the 3<sup>rd</sup> dimension according to the perspective of the scene.

The 3D cube models were first imported into the Rhinoceros 3D program. Then, they were passed to a script created by the author in the Grasshopper tool. The Grasshopper script receives individual data for each geometry, once the geometry data is transferred to the relevant parameters, the script promptly generates the distances between all the source objects and provides their names as the output.

The Grasshopper output data is exported to an Excel database. The relationships between source objects are represented as Relationship Type Parameters (RTP), categorized into close (X), medium (Y), and far (Z). Object volumes are also collected and included in the Excel file. The overall scene's entropy value is calculated by summing individual calculations using RTP and Shannon's entropy formula (1948).

To derive the Overall Object-Proximity Relationship parameter (OOPR), the RTPs and their corresponding source object labels are combined (e.g., BDX, DDX). The Unique Relationship (UORP) is formed from the Object-Proximity parameter. Entropy calculation is then performed between the OOPR and UOPR numbers.

The entropy values of each scene were compared with player ratings of the games, as well as asset count, variety, and qualitative observations regarding dominating clustering, and homogeneity effects. The data showed compatibility between these factors. The entropy values obtained from the study were also predicted through regression, leading to a meaningful and conclusive result. The study provides an objective perspective on virtual environment design, and the entropy values obtained from scenes could serve as a good reference for achieving strong composition in the early stages of design.

This study offers a method proposal by combining design, computational design, and objective measurement methods with a multidisciplinary perspective; It can be enriched with methods such as the use of artificial intelligence, different representation methods, more variety, and more game selection. If the proposed method is developed, it has the potential to approach the abstract concept of "successful virtual space" in an objective manner.

## **3B OYUN MEKANLARININ OYUN VARLIKLARI ARASINDAKİ MESAFESİ ÜZERİNDEN ENTROPİ TABANLI BİR ANALİZ YAKLAŞIMI**

### **ÖZET**

Bu çalışmanın temel amacı, entropi yöntemi aracılığıyla sanal mekan elemanlarının 3B (3 boyutlu) kompozisyonlarını sistematik olarak ölçmektir. Sanal mekandaki varlıkların 3. boyuttaki ilişkisini analiz ederek, sanal mekan tasarımı sürecine objektif bir bakış açısı ile yaklaşmak ve tasarımın sanal ortama taşınması sürecini yakalamak hedeflenmektedir. Metaverse, AR, VR gibi konseptlerin insan hayatındaki yerinin büyümesiyle birlikte yeni bir dünya tasarımının şekillendiği tespit edilmiştir. Bu yeni tasarımın anlaşılması ve belki de rehberlik sağlanabilmesi amacıyla tez çalışması sanal mekan analizine odaklanmıştır.

Entropinin estetik ilişkisi üzerine 2B imaj incelemesi ve çeşitli oyun analizlerine dair birçok yayın bulunmasına rağmen, bu çalışma, diğerlerinden farklı olarak 3B kompozisyon ayrışması, entropi ölçümü ve sanal mekan unsurlarının 3B kompozisyon analizine odaklanmaktadır. Daha önce yapılan çalışmalar sistematik bir şekilde incelenmiş ve “Mekan”ın ele alınış biçimleri tablolastırılarak, bu tablo üzerinden tez çalışması şekillenmiştir. Mekan, “Mekan Türü”, “Mekan Özelliği”, “Analiz Methodu”, “Mekan Elementi” ve “Temsil Biçimi” olarak kategorilendirilmekle beraber literatürdeki çalışmalar da bu tabloda örneklendirilmiştir.

Tez çalışmasında; oyunlara, oyunların değerlendirmelerine, oyun elementlerine erişimin kolaylığı ve tasarımı içinde barındırmasından dolayı sanal mekan türü olarak 3B oyun mekanları seçilmiştir. 11 adet bilim kurgu ve fantezi türündeki oyunlardan (God of War 4, Aion Tower of Eternity, Ghost Of Tsushima, Journey, Star Wars Jedi: Fallen Order, Elden Ring, Control, Destiny 2, Doom, Mass Effect 2, Titanfall 2), analiz için 22 sahne seçilmiştir. Oyunculardan yüksek puan alarak başarılı kabul edilen aksiyon-macera veya RPG ve üçüncü şahıs oyun türleri seçilmiştir. Fiziksel dünya yerine sanal dünyanın kompozisyonunun araştırılması amaçlandığından, gerçekliği kopyalamak yerine geleceğe yönelik tasarımlar içeren bilim kurgu türündeki oyunlar çalışmaya dahil edilmiştir. Oyunlar oyuncuların yorumlarına göre analiz edilmiş ve çalışmaya aktarılmıştır. Sahne seçerken ise, sahnedeki varlıkların ölçülebilir bir kompozisyonu olmasına ve mümkün olduğu kadar oyunun kimlik sahnesi olmasına dikkat edilmiştir.

Bu araştırma, “pictorial space” olarak adlandırılan pasif 3B oyun varlıklarını temel elemanlar olarak seçmiştir. Oyunların kaydı üzerinden elde edilen 2B imajlar kullanılarak varlıklar manuel olarak ayrıştırılmıştır. Seçilen sahnelerde bulunan 3B oyun varlıkları “source objects (kaynak obje)” olarak isimlendirilmiştir. Kaynak objeler benzerliklerine göre kategorize edilmiştir. Aynı türdeki objeler aynı harfle etiketlenmiştir. Tüm oyunlardaki kaynak obje etiketleri ve özellikleri Excel tablosuna aktarılmıştır.

Seçilen oyunlardan 2B ekran görüntüleri alınmış ve Maya modelleme programına yerleştirilmiştir. 3B küp modeller sahnenin perspektifine göre, oyun varlıklarının

sınırlarını kapsayacak biçimde öncelikle 2 boyutta yerleştirilmiştir. Daha sonra plan düzleminde perspektife göre küplerin konumu değiştirilerek 3B temsil elde edilmiştir. 3B küp modeller, Rhinoceros programına aktarılmıştır. Daha sonra, bu modeller Grasshopper aracında araştırmacı tarafından oluşturulan bir koda iletilmiştir. Grasshopper kodu her geometri için ayrı veri almakta ve modellerin verisi ilgili geometri parametrelerine aktarıldıktan sonra kod, tüm kaynak objeler arasındaki mesafeleri hesaplamaktadır. Mesafeleri, obje etiketlerini ve obje hacimlerini çıktı olarak verir.

Grasshopper çıktı verileri Excel veritabanına aktarılmıştır. Her sahne için ayrıca oluşturulan Excel sayfaları, Ekler'de paylaşılmıştır. Kaynak nesneler arasındaki ilişkiler İlişki Türü Parametreleri (RTP) olarak temsil edilmiş ve yakın (X), orta (Y) ve uzak (Z) olarak kategorize edilmiştir. Nesne hacimleri verileri de toplanıp ve Excel dosyasına dahil edilmiştir. Genel sahnenin entropi değeri, RTP ve Shannon'ın entropi formülü (1948) kullanılarak hesaplanmıştır.

Overall Object-Proximity Relationship parametresi (OOPR) elde etmek için RTP'ler ve ilgili kaynak obje etiketleri birleştirilmiştir (örneğin, BDX, DDX). Unique Object-Proximity Relationship (UOPR) parametresi ise OOPR parametrelerindeki element türleri sayısından oluşturulmuştur. Ardından OOPR ve UOPR numaraları arasında entropi hesaplaması yapılmıştır. Bir başka ifadeyle, element türü sayısı toplam element sayısına bölünerek frekans ve frekans ile de entropi hesaplanmıştır. Çeşitliliği ve belirsizliği ölçebilmesinden dolayı estetik, sanat gibi soyut alanlarda kullanılan entropi, tez çalışmasında nesnel ölçüm aracı olarak kullanılmıştır.

Hesaplamalar sonucu, çoğu sahnenin entropi değeri (0.4 ve 0.52 aralığı) birbirine yakın bulunmuştur. Bunun sebebinin benzer puanlar almış oyunlar seçilmesinin yanı sıra; benzer sahne ve yöntemlerin kullanılması da olabileceği tahmin edilmiştir. Her sahnenin entropi değeri, oyunların oyuncu puanlarıyla, varlık sayısı, çeşitlilik ve hakimiyet, yığılma ve homojenlik etkileriyle ilgili nitel gözlemlerle karşılaştırılır. Veriler, bu faktörler arasında uyumluluğu gösterir. Çalışmadan elde edilen entropi değerleri ek olarak regresyon ile kestirilmiştir. Hesaplamalar sonucu, Entropi değişkeni ile yordayıcı değişkenler (Element Sayısı, Element Tür Sayısı, Mesafe Frekansı, Obje Hacmi Frekansı, Metacritic Puanı) arasındaki çoklu korelasyon 0,781501839 olarak bulunmuştur ki bu da Entropi değişkenindeki varyansın %61'inin yordayıcı değişkenlerdeki değişimlerle açıklanabileceği anlamına gelmektedir. Tahmin hatası 0,067566312 olarak bulunmuştur. Çoklu regresyon denklemi ise 0,05'e yakın anlamlı ( $p=0,005901695$ ) bulunmuştur. Bu nedenle, yordayıcı değişkenler entropi değerlerini tahmin etmek için kullanılabilir. Entropi değerini tahmin etmek için en etkili faktör "Element Tür Sayısı" değişkeni olarak bulunmuştur.

Çalışma, sanal ortam tasarımı konusunda objektif bir perspektif sunar ve sahnelerden elde edilen entropi değerleri, tasarımın erken aşamalarında güçlü bir kompozisyon elde etmek için iyi bir referans olabilir. Multidisipliner bir bakış açısı ile tasarımı, hesaplamalı tasarımı, objektif ölçme yöntemlerini bir araya getirerek bir method önerisi sunan bu çalışma; yapay zekâ kullanımı, farklı temsil yöntemleri, daha çeşitli ve daha fazla oyun seçimi gibi yöntemler ile zenginleştirilebilir. Element seçimi, oyunların ve oyunlardan sahne seçimi manuel olarak yapılmıştır. Manuel seçim çalışmanın özerkliği olarak yorumlanabileceği gibi, seçimin otomatikleştirilmesi daha ölçülebilir sonuçlar verecektir. Araştırmacının önerileri arasında analiz edilen oyun sayısının artırılması, farklı oyun türlerinin (yüksek ve düşük puan alan oyunlar da dahil) seçilmesi, sahneleri tek bir imaj karesi ile temsil etmek yerine imaj sekansı

seilmesi, regresyon yntemi ile sonuları analiz ederken farklı yordayıcılarla alışılması verilebilir. Ek olarak, oyun seimi kriteri olan oyunculardan alınan puanlar da tartışmaya açıktır, mekanın başarısı farklı yöntemlerle de llebilir ve entropi ile karşılaştırılabilir.

alışma sonucu nerilen yntemin, ok soyut bir kavram olan “başarılı sanal mekan” tasarımına nesnel bir şekilde yaklaşma potansiyeli olduėu bulunmuştur. Daha byk bir kapsamda ele alınıp geliştirilmesi nerilmektedir.





## **1. INTRODUCTION**

### **1.1 Shaping a New World: Virtual Spaces**

Space refers to a 3D setting that can be shaped and characterized by various elements, including movement, scale, light, and materiality. From an architectural perspective, the notion of space encompasses not only physical built environments but also digital and cinematic realms. Architectural studies investigate the sensory, perceptual, and emotional dimensions of space, exploring the experiential aspects of spatial encounters. The sensory dimension of space encompasses the audible, visual, and tactile sensations evoked by a particular environment. The perceptual dimension focuses on how the human mind processes and organizes spatial information, encompassing aspects such as navigation and orientation.

A virtual environment, on the other hand, is an artificially created setting generated through computer graphics and other digital technologies, aiming to simulate either real or imagined spaces. The creation process of a virtual environment involves several stages, including conceptualization, design, development, testing, and deployment.

Throughout history, humanity has witnessed significant advancements, discoveries, and subsequent adoption of new ways of life. Currently, there is a widespread belief that the future way of life for humanity will exist within the virtual world. Although hundreds of thousands of individuals currently experience the virtual world through gaming and now through metaverses, it is anticipated that advancements in technology will make this reality accessible to every individual.

In recent years, virtual environments have gained popularity and have found application in various domains, including gaming, entertainment, education, and healthcare, thanks to advancements in technology and digital media. This growing prevalence of virtual environments represents a transformative shift in the perception and design of space. As these settings become more advanced and widely accepted, it can be expected that new architectural styles specifically tailored for these digital realms will emerge. With the increasing utilization of experiences like virtual reality

(VR), extended reality (XR), WebXR, and the metaverse, it is predicted that people will spend a significant portion of their time in virtual environments in the future. Consequently, a new world is taking shape, demanding architectural design principles to accommodate it.

The integration of computer games into future architecture is recognized as a crucial factor contributing to the experimental nature of architectural design and spatial fiction. Given its interdisciplinary design process, the incorporation of computer games in architecture merits a distinct field of study within the discipline (Yiğiter & Tatar, 2019). The objective of this study is to analyze virtual environments, aiming to explore the emerging trends in virtual architecture and design that will shape the future, and to gain insights into the novel world that has been created.

## **1.2 Scope and Purpose**

The importance of architectural design in shaping human life cannot be denied. As human life increasingly moves into the virtual world, it implies that architecture, aesthetics, experience, excitement, discoveries, and even the sense of living will also exist in the virtual realm. Such a transformation, the evolution into the virtual, needs to be thoroughly researched, analyzing the changes and developments in design during the transition to the virtual world and, if necessary, establishing regulations. By providing a framework for designing virtual environments, this research aims to understand and interpret the evolution of architecture in the virtual realm.

In order to comprehend the role of design and architectural design in the virtual world, numerous publications on the analysis of virtual environments have been examined, and the classification of the virtual environment has been established.

Among the various methods used to analyze virtual design, a specific approach was chosen to examine existing virtual designs. It was hoped that by identifying an objective relationship within successful virtual spatial designs of today, this relationship could serve as a key, guide, or even a rule for design, at least from one perspective. Computational design methods were explored to objectively identify this relationship, and a new analysis method was proposed using the entropy method.

Game environments are selected as existing virtual spaces. It is believed that analyzing game spaces will provide valuable insights into the future of the virtual world as games have been part of human life for a long time.

By analyzing computer-based games, architectural design guidelines can be established for future virtual worlds. This study aims to develop design criteria within an immersive environment. To achieve this goal, it is crucial to conduct in-depth research on the context and significance of future spaces, starting with an initial analysis of current physical spaces.

The primary objective of this study is to employ an entropy-based approach to systematically quantify the 3D compositions of successful virtual worlds. By examining the interrelationships among elements within the virtual environment, this research aims to capture the evaluation occurring in the transition from physical to virtual space design.

### **1.3 Hypothesis and Research Questions**

Virtual environments are being used more frequently across a variety of industries, including urban planning, game creation, and architecture. A new design world that has entered our lives that much, needs to be understood, analyzed, and even directed. In addition, designing and developing virtual environments can be labor-intensive and time-consuming. To simplify, understand and improve this process, there is a need for design decision support tools that can aid designers in the early phases of the design process. This study introduces a novel analysis approach to be used in analyzing and evaluating 3D digital game environments based on entropy calculation. The research questions of this study can be given as:

- How does the entropy-based measurement method give information about virtual spaces?
- How the future designers of virtual space can objectively measure their space in the early design stage?
- Is there a relationship between the success of existing game designs that have received user approval and entropy measurement?

In light of these questions, various methods for objectively analyzing the space have been thoroughly researched. As a result, a new analysis method aimed to contribute to the literature. Consequently, selected game scenes, as virtual spaces, were analyzed using the entropy method in 3D.



## **2. THEORETICAL BACKGROUND**

### **2.1 Games as Virtual Spaces**

As mentioned in the Introduction section, it will be a necessary study to make a series of rules in order to design virtual spaces in a systematic way. In this study, which analyzes virtual spaces in order to determine this set of rules, games are chosen as virtual spaces. The reason for choosing games among virtual spaces such as movies, architectural designs, and metaverses is that there are many examples of different types of games and they are accessible. Additionally, games offer extraordinarily detailed visual worlds that can be examined from many angles, including those relevant to the visual arts (Atkinson & Parsayi, 2020). Sailer et al. cited the following:

Video games have become increasingly popular among all age groups and genders in recent years (Entertainment Software Association, 2015), and are often considered one of the central entertainment media of the future (cf. McGonigal, 2011). Without a doubt, video games inherently possess a high level of motivational potential (cf. Garriss, Ahlers, & Driskell, 2002; Gee, 2007; Hense & Mandl, 2014; Przybylski, Rigby, & Ryan, 2010; Rigby & Ryan, 2011; Ryan, Rigby, & Przybylski, 2006; Yee, 2006) ( 2017, p. 371).

Modern video games are more suited to creating the impression of "being there" in virtual settings. Games are increasingly frequently judged on their ability to consistently evoke presence; yet, there is currently no characterized, objective present measurement (Terkildsen, Thomas; Makransky, 2019). A lot of data is needed to develop a viable test, the games have a cumulative knowledge pile with their diversity, easy access to reliable reviews, and the availability and popularity of the games themselves through different tools. It also successfully uses architecture and design. Yiğiter & Tatar (2019), finding architecture crucial for games, examine what should be the function of the architecture in the games.

Since there are many different types of games, how the game is classified, game elements, and mechanics are researched and classified before choosing a sample game

set for the study. A video game can be categorized depending on numerous aspects; including the genre, platform, story, technology, aesthetics, and gameplay mechanics:

**Platform:** Over time, platforms have changed, incorporating mobile devices and virtual reality (VR) headsets in addition to dedicated game consoles, personal computers, and other hardware. Each platform provides distinct features and experiences, which have an impact on the creation of games.

**Player count:** Games can be classified by the number of players they support, such as single-player, local multiplayer, and online multiplayer.

**Genre:** In terms of gameplay mechanics, similarities, and thematic components, video game genres classify games. The fundamental experiences that various games offer can be understood and communicated within the context of their respective genres, such as action, adventure, role-playing, strategy, simulation, sports, racing, puzzle, and many more.

**Game mechanics:** The core mechanics and dynamics of a game are defined by its mechanics. They define the game world's potential and constraints and decide how players can engage with it. The structure, objectives, and difficulties presented by these mechanics are for players to explore and overcome.

**Story:** The plot and narrative components that take place within the game's world are referred to as the story. It includes all of the elements that set the scene and guide the player's experience, including the people, places, things, and overall structure. Gamers are drawn in, their emotions are evoked, they feel immersed in the game, and they progress.

## **2.2 Fantasy & Science-Fiction Games**

As mentioned before, since this study, it is examining the transformation that the design undergoes as it moves from the physical world to the virtual world, games have been chosen among the types that can respond to this. Sci-fi and fantastic game narratives have been chosen as a priority because they have few architectural restrictions and support creative design as much as possible. Some games have spaces that simulate the real world, since the space to be measured is an artificially created composition while creating, calculating the entropies of real spaces may distract us from measuring the created. As Guzelsoy (2019) classifies computer-game spaces as

realistic and possible spaces, semi-real and improbable spaces, and surreal spaces, the analyzed space can be defined as surreal in this study.

Games that are science fiction or fantasy frequently make extensive use of environment art to build engaging and fantastic environments for players to explore. In this process, environment art is essential since it establishes the visual aesthetic, tone, and mood of the gaming universe. For instance, the complex and meticulously detailed settings in games like the Mass Effect and The Elder Scrolls series aid in establishing the distinctive settings and civilizations of those universes. The intricate and highly-detailed environments in games like Mass Effect and The Elder Scrolls series help to establish the unique settings and cultures of their respective worlds.

The gameplay and plot of science fiction and fantasy games often incorporate cutting-edge technologies or magical components. By displaying future or alien architecture, landscapes, and objects, they illustrate these ideas. Games like Deus Ex and the Tron series, for instance, use futuristic machinery and glowing neon cityscapes to establish their high-tech settings, whereas World of Warcraft and The Legend of Zelda: Breath of the Wild use fantastical settings and magical creatures to establish their magical elements.



### **3. METHODOLOGY**

Multiple methods and environmental elements can be used to formulate design rules that will reference new world creation. An environment regardless it is real or surreal, consists of multiple elements to be analyzed. Chapter 3 will provide insights into earlier scientific works and the needs of the new research subjects or solutions regarding analyzing space.

This study measures the composition of the space elements using the entropy method. This method can also be used to decompose any 3D space. The general methodology in the study can be summarized by the following steps:

- Selection of the data (types and aspects of the space)
- Selection of the analyzing method
- Determining elements of the space
- Representation techniques
- Entropy calculation

In the study, firstly spaces were analyzed and selected, then appropriate analysis methods were investigated for the measurement of the spaces. Studies analyzing 3D spaces like the architecture, and game environment in the literature have been examined, objective characterization methods have been compiled, and the most appropriate techniques for analyzing virtual space have been evaluated. Finally, the entropy method is chosen within the scope of this study to analyze 3D virtual game spaces.

#### **3.1 Selection of the Data: Aspects of the Space**

As discussed in the previous sections, space can be defined and classified in many ways. To generalize the analysis of space, the space types were examined. Architecture, city (whether physical or not), metaverse, movie, and game environments can be examples of space type. In the literature, Çatak (2003) examines

architecture in the games, in terms of playability. Kim et al. (2017) and Olsson (2017) worked on virtual space, Bostancı (2008) examined urban skylines and Zhang & Schabel (2016) chose to work on urban space in order to analyze “space”. Table 3.1 displays some of the space classifications found in the literature.

When selecting a space to analyze, it's important to consider the specific features that are relevant to the investigation. For instance, if the impact of skyscrapers on urban aesthetics is the focus of the study, the sample group should include cities with and without skyscrapers. In this study, the selected spaces were differentiated by their features, while being similar in other respects, in accordance with the methodology. Similarly, in another hypothetical study that examines the contributions of landscape elements to the metaverse environment, spaces with comparable characteristics but varying landscapes should be included in the sample. After selecting the sample spaces, the next step is to identify which aspects of these spaces can be analyzed.

### **3.1.1 Aspects of the space**

In previous studies, spaces are examined by their aesthetics, visibility, accessibility, volumetric-ness etc. referring that every aspect is crucial for the immersiveness feeling of a space. Most studies have used their analysis to measure aesthetics. Table 3.1 shows some of the space classifications that have been used in the literature.

In most studies on virtual/physical spaces, the effect of architectural elements was examined and a space usage analysis was made. Çatak (2003), in his study examining the use of architecture in games, discussed the functions of architecture in the game such as orientation, hiding, blocking, and diversification in order to examine the environment in the virtual environment.

A couple of studies, on the other hand, focus on finding, classifying, and analyzing game elements, architectural and environmental elements. The architectural aspects of the modular kits in the video game Fallout 4 were used to categorize by Statham et al. (2022) These kits comprised a primary building kit as well as kits for other environments, such as a church, a high-tech facility, an industrial plant, a steam tunnel, a cave, a house, a shanty, the institute, and others. Also, modular properties of classical architecture, open-world games, linear games, and urban planning games are compared. The researcher conducted an examination of the design stages involved in the classification of modular assets with the aim of creating an environment that is

more optimal. Furthermore, an analysis of the selected game assets utilized in the case study was carried out to determine their reproducibility (Statham, N., Jacob, J., Fridenfalk, M., Rodrigues, 2021).

In another study, in order to create a method for virtual environment design, games designed after 2000 were analyzed, 5 elements characterizing the virtual environment were found in the books written about the game theory, and how these 5 elements were used among the most popular games were analyzed. The most used combination of the sub-branches of 5 main features has been evaluated (Kim et al., 2017). Like Kim et al., Olsson also examines the game environment, from different perspectives; through the eye-tracking method. Using interactive space in that users have the camera control, instead of 2D images can be interpreted as an inclusive attempt to understand the environment (Olsson, 2017).

Most of the studies focus on aesthetics in the space. The satisfaction of players' psychological needs can be impacted by the aesthetic worth and quality of design implementations in games, claim Sailer et al. (2017). Bostancı defines the formal aesthetic evaluation criteria as diversity, visual richness, difference, line effect forming the silhouette, mass unit, vertical elements, horizontal elements, form elements, color elements, hierarchical ordering, dominant elements, repetition elements, continuity elements and time layers, clarity, readability (Bostancı, 2008). Similar to Bostancı, most of the researchers define their own aesthetic evaluation criteria.

One study glances at the virtual environment's interactivity and identifies five types of elements that help create environments that are interesting and engaging: dynamic elements, interaction, inter-active dynamic elements, dynamic interactions, and dynamic interactions with dynamic elements (Blom & Beckhaus, 2014).

In their study (Pedrinis et al., 2022), a novel technique for evaluating city visibility on a metropolitan scale is presented. In order to offer a thematic vision of the city and its urban landscape, this technique calculates the view composition in terms of the city objects visible from a specific viewpoint and creates a georeferenced and semantically rich database of those visible objects. Although it is a very valuable study in terms of systematically processing and analyzing multiple data obtained from the city, its applicability for virtual spaces is not possible due to the scattered and inaccessible data, and the need for another method remains. However, it can be applied in specific

virtual spaces where sufficient data can be accessed. While some papers work on the visibility of the urban space, a paper discusses the concept of a "volumetric city" and investigates the complex uses of volumetric urban space (Zhang & Schabel, 2016).

Another interesting approach is to reach the complexity level of the game by measuring the psychological states of the player while playing the game (Naying et al., 2022). Dealing with the importance of game environment design through the term "pictorial space", Della-Bosca et al. also measured the complexity of the scene (Della-Bosca et al., 2017).

In Güzelci & Sener's study (2019), the authors propose using entropy to gain insight into the subjective tendencies that exist in the evaluation process of architectural competitions. They utilize the Entropy-Based Design Evaluation Model (EBDEM) to assess the objectivity of the jury's evaluations and to examine how entropy values relate to competition outcomes.

McCormack & Cruz Gambardella (2022) examine the concept of complexity in the context of generative and evolutionary art and design. The authors explore various definitions of complexity and apply different complexity measures to three evolutionary art datasets, studying the correlations between complexity and individual aesthetic judgment by the artist or the physically measured complexity of generative 3D forms.

In their study, Coutrot et al. (2022) by capturing the navigation abilities of users in the space, the complexity of the physical space was measured with OSMnx. In the same study, the tasks embedded in the video game measure the navigation abilities of the players.

### **3.1.2 Differences between analyzing physical and virtual environments**

The difference between real and virtual spaces should also be taken into account while working on the space. In the literature, the differences between virtual and physical space have generally been studied within the field of educational science. In the scope of the analysis of the space, the interface in the analysis of the physical space is human sensations and perceptions, while the technological interface is added to this in the virtual space examination. In addition, the effects of navigation/transportation / spatial perspective differences on the perception of space should be considered.

An architect Olivier Azémar, talks about he examines physical environments to give game developers instances of gameplay settings (von Borries, Walz and Böttger 2007, 132-133). Similar to that, Bonner aimed to apply game theory and methodology from fields like philosophy and architecture, in his study (Bonner, 2014).

Based on this example, it can be argued that analyzing our physical world first is a powerful method to create a virtual world. Human imagination or artificial intelligence algorithms draw from the data they are given in the process of creation. Therefore, it can be said that these two environments stem from the same foundation. However, the focus of this study is to capture the differentiation that arises as it accesses unique potential that the other does not possess while differentiating itself. As a result, it is aimed that this study will make a different contribution to the literature by applying objective research methods on virtual spaces.

### **3.2 Selection of the Analyzing Method**

Space, as presented in this study, is a multifaceted entity that encompasses numerous sub-nuances. These include the colors utilized, the coherence of colors with one another, the objects present, the details of these objects, the representation of these details on the scene, their composition, scale, and the emotions that they elicit, among other factors. Analyzing a space, in general, is a comprehensive task, and in this study, while discussing the various aspects that can be analyzed in depth, a single analysis method was selected and a new approach was attempted.

In most studies, objective methods like computational approaches were used as well as subjective methods that use evaluations such as personal judgment, surveys, and experiments to analyze spaces. Computational methods have a special place in analysis because they digitize and concretize information that is difficult to work on due to its abstractness. Computational analysis methods were also investigated and applied in this study. These methods can be counted as entropy, fuzzy logic, fractal geometry, space syntax, volumetric analysis, and computer-based modeling tools, according to Bostancı (2008). Table 3.1 displays a few of the several categories used to describe space in the literature.

McCormack & Cruz Gambardella (2022), on the other hand, trying to determine how various measurements outlined in the literature correlated with unique aesthetic

assessments, tested and listed some of the methods as entropy, energy, contours, Euler, algorithmic complexity, structural complexity, Machado-Cardoso Complexity, Machado-Cardoso Complexity with edge detection, Fractal Dimension, and Fractal Aesthetic. In this study, some of the methods that can be used for virtual space analysis are examined.

### 3.2.1 Entropy measurement

Entropy, which is defined as a reference to the disorganization tendency in nature, has gained knowledge when used in the field of information. Entropy is a measure of the amount of disorder or randomness in a system. It is often used in physics, information theory, and other fields to describe the degree of uncertainty or unpredictability in a system. Shannon's entropy (1948), named after Claude Shannon, is a specific type of entropy used in information theory.

The main reason why entropy is used to measure abstract features in fields such as art, design, and architecture is that it can measure the diversity that affects aesthetics and success. The usability of the entropy method in aesthetics and in providing measurability has been determined (Bostancı, 2008). In this study, entropy was chosen as the analyzing method because the measurability of the spaces was investigated through the tool produced for the construction of virtual spaces.

$$H = - \sum_{i=1}^{n \text{ level}} p_i \log_2 p_i . \quad (1)$$

As Güzelci et al. redefined the entropy Eq (1):

In the basic entropy Eq. (1) (Stamps 2002; Crompton 2012),  $p$  refers to the probability of occurrence of each element in a given whole. The frequency of the element and the number of total elements define the  $p$ -value. To calculate the  $H$  value of each element, the mathematical operation  $\log_2 p_i$  is applied and

multiplied by the pi itself. The overall H value of a given whole is the result of the sum of each element's H value (Stamps 2004; Crompton 2012) ( 2021, p. 88).

Many studies had examined entropy in order to measure navigation, complexity, architectural competitions, aesthetics, patterns, and pleasure (Coutrot et al., 2022; Güzelci et al., 2021; Güzelci & Sener, 2019; McCormack & Cruz Gambardella, 2022; Stamps, 2002, 2003).

In this study, entropy is used as the basic entropy Eq. (1) Güzelci et al., offer a computational approach to calculate the entropy of 2D geometric patterns called muqarnas. Similar to Stamps' (2004) technique of representation, the components of the 2-dimensional muqarnas patterns are expressed through alphabetical symbols( 2021).

There are different approaches to the interpretation of the calculated entropy values. In her thesis, Bostancı (2008) analyzed the entropy values in the Gaussian distribution curve and defined the appropriate values according to the graph (Figure 3.1). Values below the appropriate range were evaluated as monotonous according to entropy, while values above them were given a chaotic definition.

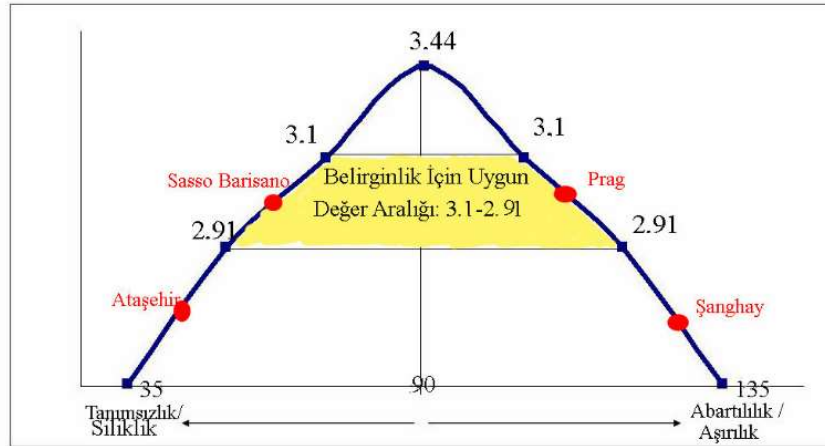


**Figure 3.1:** Gaussian distribution curve of entropy, image taken from Bostancı's (2008) thesis. The curve indicates a "Range of values suitable for clarity", ranging the values from unidentifiability to extremism.

### 3.3 Categorization of the Space Elements

In order to develop a novel methodology for measuring specific aspects of a space, it is essential to first classify the elements of that space. This classification can be achieved through an extensive review of the literature on space and its elements. Kevin Lynch's "Image of the City" provides a solid foundation for the categorization of city elements as the path, landmark, edge, node, and district (Lynch, 1960). This classification and its various derivatives can also be applied to the game, metaverse, and movie locations. Similarly, the basic design qualities that are fundamental to all branches of art, as outlined as harmony, contrast, symmetry, and rhythm by Özer (1993), can be adapted to the elements of 3D spaces. Some of the classifications of the space in the literature can be seen in Table 3.1.

The use of such classification systems is particularly used in the evaluation of space aesthetics. It allows for a comprehensive assessment of the elements that contribute to the overall visual appeal of a space. This, in turn, can enable designers and architects to manipulate these elements to achieve specific aesthetic goals. Additionally, the classification of space elements can aid in the evaluation of other aspects such as complexity, success, and navigation.

**Table 3.1:** Categorization of the term “Space” according to earlier studies.

| Space Categorization<br>References | Space Type                            | Space Aspects                                                                                        | Analyze Method          | Space Elements                                                                                                                                                                                                                              | Representation Technique |
|------------------------------------|---------------------------------------|------------------------------------------------------------------------------------------------------|-------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------|
| Bostancı, 2008                     | Urban Skylines                        | Aesthetics                                                                                           | Entropy                 | -Skyline<br>-Mass unit<br>-Vertical elements<br>-Horizontal elements<br>-Elements of form<br>-Elements of color<br>-Hierarchical grading<br>-Elements of dominant effect<br>-Repetition elements<br>-Elements of continuity<br>-Time layers | 2D Images                |
| Kim et al., 2017                   | Virtual Landscape in Game Environment | -Story<br>-Space shape<br>-Space and action<br>-Dimensions<br>-User complexity<br>-Interaction level | Database Classification | -Generating / Face / 3D-3D / Single / Partial<br>-Providing / Chain / 3D-3D / Single / Partial<br>-Providing / Linear / 2D-2D / Single / Partial                                                                                            | Database Classification  |

**Table 3.1: (continued)** Categorization of the term “Space” according to earlier studies.

| Space Categorization in the Literature | Space Type                   | Space Aspects              | Analyze Method                                                                  | Space Elements                                                                                                                              | Representation Technique |
|----------------------------------------|------------------------------|----------------------------|---------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------|--------------------------|
| Çatak, 2003                            | Game Environment             | Architecture (Playability) | Observation                                                                     | -Orientation<br>-Hiding<br>-Blocking<br>-Diversification                                                                                    | Interpretation           |
| Olsson, 2017                           | Game Environment             |                            | Eye-tracking                                                                    |                                                                                                                                             | Interactive Space        |
| Zhang & Schabel, 2016                  | Urban Space                  | Volumetric Generation      | Mapping: redefining ground exploring movement modes analysing layered functions | -Compactness<br>-Space proximity<br>-Verticality<br>-Intensive mixed uses                                                                   | Multiple                 |
| Girginkaya & Çağdas, 2007              | Virtual Environment          | Movement                   | Space Syntax                                                                    | -Identity<br>-Scale<br>-Audio<br>-Visual components<br>-Its users                                                                           | 3D Virtual Simulation    |
| Statham et al., 2022                   | Game Environment (Fallout 4) | Modular Architecture       | Database Classification                                                         | -Wall Panels<br>-Transition Points<br>-Floors and Roofs<br>-Corridor Modules<br>-Trims<br>-Vertical –Transitions                            | 3D Modular Kit Model     |
| Lynch, 1960                            | City                         | City Image                 | Observation                                                                     | -Path<br>-Landmark<br>-Edge<br>-Node<br>-District                                                                                           | Database Classification  |
| e-Library: Quixel Megascans            | Game Environment             |                            |                                                                                 | -Buildings / historical<br>-Buildings / industrial<br>-Nature / plants<br>-Nature / rocks<br>-Soil etc<br>-Path / Street                    | 3D Model                 |
| Blom & Beckhaus, 2014                  | Virtual Environment          | Interactivity              | Observation                                                                     | -Dynamic elements<br>-Interaction<br>-Inter-active dynamic elements<br>-Dynamic interactions<br>-Dynamic interactions with dynamic elements | Database Classification  |

### 3.4 Data Representation, Data Loss

After space, elements, and analyzing method are determined, space must be represented in order to measure it. As this study focuses on virtual 3D spaces, examining them requires a representation of software on a PC. In the literature, there are various studies to use different techniques to represent 3D data.

Güzelci et al. (2021), present a computational model for measuring the entropy value of 2-dimensional geometric patterns, with a focus on muqarnas patterns in Classical Ottoman architecture. To apply the model to muqarnas patterns, the authors convert raster images of the patterns of the buildings into a vector format. This way, they created 2D demonstrations of a 3D object. The majority of studies have utilized 2D models, while 3D representations have been less commonly employed.

Space Syntax, a frequently used space analysis method, examines spatial configurations. Girginkaya & Çağdas (2007), while comparing real and virtual environments, represented the space as a 3D Virtual Simulation and tested the Space Syntax program on this 3D model. Like them, in one study 3D Model is created both for analyzing and representing it (Pedrinis et al., 2022).

The sample collection method can also be determined according to the represented method to be used. If the place exists in the physical world, its information can be obtained by methods such as assigning point clouds, taking a survey, and taking pictures. If digital areas such as movies, games, and metaverse spaces will be explored, it can be used directly if the 3D version already exists. Or it can be remodeled with a modeling program and represented in 3D. Optionally, lots of 3D spaces are worked through 2D representations over their screenshots, in the literature.

In order to ensure the validity and reliability of measurement results, it is crucial that the data collected from different sources are comparable. If the data vary in certain aspects, the measurement results may not accurately represent the intended feature. To enable the selection of comparable data, common and distinguishing characteristics of the data can be identified. Such characteristics may include similar production styles, use of the same game engine, influence of the same art movement, use of similar color palettes or cinematography techniques, and so on. When representing data, it is important to use similar techniques to capture comparable samples. For instance, if photographs of a building are to be taken in the real world, or screenshots from virtual

environments are to be captured, factors such as the adjusted perspective angle, scale, lighting in the environment, and details of readability should be taken into consideration. To obtain comparable samples, Bostancı (2008) compared postcards with city silhouettes. Pedrinis et al. (2022), examined the input parameters such as viewpoint, field of view, and resolution while working on measuring visual composition.

Data loss is inevitable in all scenarios where all the exact properties of the analyzed object are not taken. In the study, a data representation method should be chosen so that the erroneous calculation caused by data loss can be minimized.

### **3.5 Proximity Calculation**

In this study, the composition relations of the space elements were calculated over the proximity between them. There are many methods to calculate the distance or proximity between objects. Proximity calculation methods may also change depending on the type of data and which software will be used for analysis. Generally, distance is calculated using different methods using the center and volume information of the objects.

Guang-yu (1998), utilizes a technique that measures the distances between 3D objects using their surface normal vectors. Hoff et al. (2001) developed a new algorithm that executes proximity queries to compute intersections, separation distances, penetration depths, contact sites, and normals in addition to detecting collisions in order to calculate 2D geometric proximity.

### **3.6 Importance of the Study**

The study presents a methodology for calculating the compositional relationships of elements in any space by any method. First of all, the space was examined according to its use in the literature. According to the previous studies, space is categorized as space type, space aspect, analysis method, space element, and representation techniques (Table 3.1). It is hoped that the systematic study of space will facilitate future studies.

There are studies that utilize entropy as a measure of complexity and evaluate aesthetic quality in various domains. Bostancı (2008) proposes using entropy to evaluate the

aesthetical quality of urban skylines, while Güzelci et al. (2021) present a computational model for measuring the entropy value of 2-dimensional geometric patterns. McCormack & Cruz Gambardella (2022) examine the concept of complexity in generative and evolutionary art and design, applying different complexity measures to three datasets and assessing their correlations with aesthetic judgment. The study of Della-Bosca et al. (2017) also analyzes the game environment design with computational methods. Differently, it uses the fractal method and chooses an immersive puzzle game genre. The box-counting method used in the analysis, on the other hand, has achieved a 2D analysis rather than a composition relationship since it reduces the 3D space to 2D from a single perspective.

This study differentiates from previous publications by focusing on 3D decomposition, entropy measurement, and 3D composition analysis of virtual environments.

#### **4. AN ENTROPY-BASED ANALYSIS APPROACH FOR 3D GAME ENVIRONMENTS UTILIZING PROXIMITY OF GAME ASSETS**

In this section, the details of the study are presented with respect to the case study. In general, the selection and reasoning behind the chosen games, the selection of scenes from the chosen games, the classification of 3D assets present in the scenes, and the calculation of relationships between the assets have been emphasized. The goal is to understand the 3D relationships between objects and analyze the composition of the space by listing types of proximity and adjacency relationships between boxes. This will allow for the measurement of the total entropy of the space.

In the scope of this study, 22 scenes from 11 science-fiction, fantasy game narratives were selected to be analyzed. The games, such as action-adventure, RPG genres, and TPS games, were selected based on their high scores from players (Ur-01). A 3D representation of selected games was created using 2D visuals taken from the games. The optimal entropy value is investigated by analyzing the entropy of selected game environments in comparison to their Metacritic scores, distance, and object volume variety. The results showed that the entropy values of game scenes were consistent with game review scores and qualitative and quantitative observations. This study provides an objective perspective on virtual environment design, and using the entropy values for achieving strong composition could be a useful tool in the early stages of design.

##### **4.1 Selection of the Games, Scenes**

After examining various types of spaces discussed in the literature, game environments have been chosen for analysis. Game environments prioritize architecture and offer easier access and analysis of data. Furthermore, game environments allow for design beyond the constraints of the physical world, enabling exploration of how architectural design has evolved and could continue to evolve.

As the environment and architectural metamorphism are key elements in this study, games are selected accordingly. Different lists were found with keywords such as "games with best environments", "best sci-fi games", "best utopic buildings in games", "best game rankings" from websites that rank games according to different topics, finally mostly the TPS games with action-adventure and RPG genres were selected (Igor, 2023; Walia, 2022). Among the selected games, those that were deemed successful according to the data from Metacritic and Steam websites were chosen (Url-01, Url-02). To investigate the composition of virtual worlds rather than physical worlds, futuristic and science-fiction narratives were chosen instead of game narratives that mimic reality.

When selecting game scenes, priority was given to those with architecturally distinctive environments. Scenes with similar perspectives and area scales were chosen to allow for comparisons between them. The selected games used a human-scale and eye-level-based camera angle.

A total of 22 game scenes (2 scenes per game) were selected from 11 games (God of War 4, Aion Tower of Eternity, Ghost Of Tsushima, Journey, Star Wars Jedi: Fallen Order, Elden Ring, Control, Destiny 2, Doom, Mass Effect 2, Titanfall 2) to be analyzed (Figure 4.1). Two scenes were chosen from each game to observe the relationships between the scenes within the same game. All of the selected games are highly regarded by players, have been downloaded frequently, and have gathered significant attention. Their space designs contain numerous creative elements and incorporate approaches that challenge the future of environmental design.

#### **4.1.1 Selected games**

##### **4.1.1.1 God of War**

God of War 4 is an action-adventure game in a highly stylized mythology-inspired environment. The game environment is highly liked by gamers regarding its incredibly detailed assets, featuring beautiful and intricate patterns. The game's muted color scheme emphasizes earthy tones and blues, creating a gloomy and atmospheric feel. The settings are both large and intricately detailed, with a strong emphasis on establishing a feeling of scale. While choosing the scene from this play, it was felt that the compositions of the assets were strong. The scale difference in the assets gave a dominant effect on the objects considered sacred in the narrative. The holistic

atmosphere given by the successful use of detailing, light, shadow, and fog elements in the model of the objects stood out.

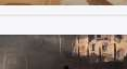
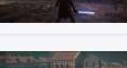
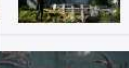
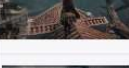
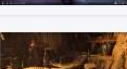
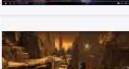
| Scene 1                                                                             | Scene 2                                                                             | Game Title                  | Genre            | Narrative          | Composition            | Art Style          | Technical               | Characteristics            |
|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|-----------------------------|------------------|--------------------|------------------------|--------------------|-------------------------|----------------------------|
|    |    | God of War 4                | Action-Adventure | Epic/ Mythological | Strong, Dynamic        | Fantastic Realism  | High-fidelity, detailed | Obscure, Mythology         |
|    |    | Aion Tower of Eternity      | RPG              | Fantasy            | Intricate, Layered     | Stylized           | High-fidelity, detailed | Surreal, Otherworldly      |
|    |    | Ghost Of Tsushima           | Action-Adventure | Historical Fiction | Harmonious, Natural    | Photorealism       | High-fidelity, detailed | Realistic                  |
|    |    | Journey                     | Adventure        | Exploration        | Minimalist, Abstract   | Low Poly, Stylized | High-fidelity, polished | Mystic, Metaphysical       |
|    |    | Star War: Jedi Fallen Order | Action-Adventure | Science Fiction    | Varied, Cinematic      | Fantastic Realism  | High-fidelity, detailed | Dystopic                   |
|    |    | Elden Ring                  | RPG              | Fantasy            | Intricate, Layered     | Fantastic Realism  | High-fidelity, detailed | Mystic                     |
|    |    | Control                     | Action-Adventure | Mystery            | Nonlinear, Exploration | Metaphysical       | High-fidelity, detailed | Intricate world-building   |
|   |   | Destiny                     | MMO              | Science Fiction    | Intricate, Layered     | Fantastic Realism  | High-fidelity, detailed | Multiplayer focus          |
|  |  | Doom                        | FPS              | Fantasy            | Intricate, Layered     | Fantastic Realism  | High-fidelity, detailed | Brutal gameplay            |
|  |  | Mass Effect 2               | RPG              | Science Fiction    | Strong, Dynamic        | Fantastic Realism  | High-fidelity, detailed | Rich storytelling          |
|  |  | Titanfall 2                 | FPS              | Science Fiction    | Strong, Dynamic        | Fantastic Realism  | High-fidelity, detailed | Unique pilot-mech dynamics |

**Figure 4.1:** Selected games, scenes, and their aspects

Based on the reviews on the Metacritic website, God of War received overwhelmingly positive feedback from critics (Url-05). The game was praised for its gameplay, narrative structure, visuals, combat, and exploration. The combat system was generally well-received, although some reviews mentioned concerns about a lack of enemy variety. The game's narrative, which focused on Kratos' redemption and his relationship with his son Atreus, received high praise for its emotional depth and character development. Critics also highlighted the game's stunning visuals, cinematic presentation, and attention to detail.

This game has been chosen because of the valuable comments and high scores it has received. The game's captivating world design deserves a closer examination due to the creative and aesthetically pleasing designs utilized in its game space.

#### **4.1.1.2 Aion Tower of Eternity**

MMORPG Aion Tower of Eternity has a fantasy theme. With its vibrant colors and ornate embellishments, the game's setting is highly stylized and intended to convey awe and magic. Tall buildings and elaborate patterns are used to create environments that give the impression of a vast, secretive universe. The goal of the environment design is to create an unreal world by combining items that have been drastically shrunk back from their original size and by applying unusual color combinations.

Positive reviews have been given to Aion: The Tower of Eternity for its gorgeous graphics, and flawless gameplay (Url-06). It is hailed as the most attractive MMORPG, providing a satisfying experience with fun challenges. Both new and experienced players find it to be a good alternative if they're looking for a different plot and a change from other popular MMOs. One of the users, nicknamed "NegativeCreep" emphasized that even though Aion has great graphics, playing creates a monotonous feeling as it repeats the same action (Url-06).

Aion is selected among other higher-scored games because its graphics and world creations are highly liked by players. Low scores are given because of the mechanics, according to reviews.

#### **4.1.1.3 Ghost of Tsushima**

A historical, traditionally Japanese-influenced environment serves as the backdrop for the action-adventure game Ghost of Tsushima. The game's scenario is very realistic and intricate, with an emphasis on creating an atmosphere of authenticity that transports the player to a different era and location. Although in this study realism in games is not appreciated, Ghost of Tsushima was chosen since it used original tunes. Warm colors that arouse longing and despair are heavily emphasized in the striking color scheme. With an emphasis on creating a sense of immersion, the landscapes are both solid and richly detailed.

The user reviews for Ghost of Tsushima are generally positive, with many users praising the game's combat, open world, and graphics (Url-07). Some users consider

it one of the best games they have ever played, highlighting the fluid combat, vast open world, and rewarding gameplay. The game's exploration and art style is also highly regarded, with comparisons to *The Legend of Zelda: Breath of the Wild*. Users appreciate the attention to detail in the world design and find the combat system deep and enjoyable. However, there are a few negative reviews as well. Some users criticize the game for being a stale open-world experience with a lackluster story and mechanics. These users express disappointment with the game's lack of originality and find it overrated. Some also compare it unfavorably to other games, such as *Assassin's Creed*, and find it to be a generic open-world game with uninteresting side activities.

Even though futuristic, unreal environments are considered for the study, *Ghost of Tsushima* is also selected as the arrangement of the assets is found appealing, original, and worth analyzing.

#### **4.1.1.4 The Journey**

Awe and amazement are evoked by the highly stylized, abstract atmosphere of the independent video game *The Journey*. The use of vibrant, dramatic colors highlights an amusing, magical atmosphere. The partial element utilization and placement in the middle of the void while maintaining a strong composition feeling in the environment design are both highly intriguing. Through its environment's mystical and appealing surroundings, the game inspires a sense of exploration. The camera system emphasizes the feeling of floating around the environment in an effort to offer the player a sense of freedom.

Based on the user reviews, opinions about the game *The Journey* are varied. Some users describe it as a deep and philosophical experience that evokes profound thoughts about existence (Url-08). They praise the game's unique qualities, such as its visuals, music, and emotional impact. These players find value in the game's short length and replayability. On the other hand, some users criticize the game for its brevity, lack of replayability, and simplistic gameplay. They argue that it offers little challenge and fails to meet their expectations in terms of story and gameplay mechanics. These users believe that the game's artistic elements are not enough to compensate for its perceived shortcomings.

#### **4.1.1.5 Star Wars Jedi: Fallen Order**

The Star Wars Jedi: Fallen Order sci-fi franchise has stylish and highly detailed environments. With a unique and creative setting that seems to exist in the Star Wars world, the color scheme is diversified. The expansive and complex settings used in the environment design are meant to give the observer a sense of magnitude. One of the scenes that was chosen demonstrates how they produced a scene with incredibly few but sophisticated pieces.

The critics' opinions on Star Wars Jedi: Fallen Order are varied. Some praised the game for its graphics, sound design, and attempt to create a compelling Star Wars story (Url-09). Players enjoyed the light saber combat and appreciated the detailed maps and lore integration. However, others criticized the game for its excessive platforming and puzzles, which they found tiresome. They felt that the story was hard to follow and the characters lacked depth. The gameplay was seen as frustrating and glitchy by some, while others found the combat mechanics and control to be clunky.

Although the game received a low score compared to other games due to some bad comments, it was not seen that these comments were directed at the environment design. In addition, the game was chosen for analysis because of its interesting architectural design elements, and taking place in the future.

#### **4.1.1.6 Elden Ring**

Elden Ring is a fantasy action role-playing game with a highly stylized environment that emphasizes mysticism and the supernatural. The color scheme is muted, which gives the scene a dark, moody sense. The settings are vast and detailed in an effort to inspire a sense of exploration. Additionally, it has been noted that the participant feels crowded because of how closely the scene's objects are placed near one another.

Some users are praising the game for its beautiful graphics, addictive gameplay loop, and challenging boss fights story (Url-10). They mention being immersed in the game and spending a significant amount of time playing it. These players seem to enjoy the exploration aspect and the rewards they receive for venturing off the beaten path.

On the other hand, some users express disappointment with the game, mentioning frame drops, repetitive loot tables, bugs and glitches, and an empty or boring open world. They compare it unfavorably to other FromSoftware games like Sekiro and

criticize aspects like graphics, balance, fights, story, and the time required for exploration.

#### **4.1.1.7 Control**

Control is unique for its striking architectural style and futuristic surroundings. The game's environments have a combination of symmetrical and dynamic aspects despite being primarily indoor-based. The ambiance is unique and visually appealing due to the clear impact of modern architecture. The color scheme and lighting in the game contribute to its overall aesthetic, emphasizing the atmosphere of fascination and mystery. By effectively combining the familiar with the spooky, Control's environment design creates a compelling and visually appealing universe.

Some users found the game to be enjoyable, praising its interesting world, graphics, story, and atmosphere (Url-11). They appreciated the unique gameplay mechanics and the immersive experience it provided. However, there were also negative reviews mentioning issues with the combat, repetitive gameplay loop, poor navigation, confusing plot, and technical problems like texture bugs and frame rate drops. Some users felt disappointed by the game, while others found it to be a masterpiece or highly entertaining.

Control has been selected primarily due to its strong architectural design and futuristic narrative, despite mostly taking place in an unstable semi-indoor environment. Symmetry prevails within the space, particularly in the overall asset organization. While modern architectural influences dominate, the skillful incorporation of the aesthetic aspect elevates the game to a valuable position from an architectural standpoint.

#### **4.1.1.8 Destiny 2**

Destiny is recognized for its elegant and carefully crafted spaces that perfectly capture the sci-fi genre. The enormous and complex Destiny franchise universe serves as the setting for the game. The environments inspire awe and majesty with their varied color palette. The rich ambient design attempts to immerse players in a visually appealing universe that highlights the scope and beauty of the sci-fi concept.

It is noteworthy that the difference between the scores of the Destiny game from users and experts on the Metacritic site is high. "Critic Reviews" are generally positive,

praising the game for its improved graphics, sound effects, content, and overall experience compared to the original *Destiny* (Url-12). Many reviewers mentioned that *Destiny 2* exceeded their expectations and delivered a satisfying sequel. The game was commended for its engaging campaign, rewarding gameplay, and the amount of content available to players. On the contrary, “User Reviews” was more negative (Url-13). Many players feel that *Destiny 2* is more like an expansion or a rehash of the first game rather than a true sequel. They expected more new content and features but found it to be lacking. Some users mentioned that *Destiny 2* didn't introduce enough new enemies, classes, or subclasses. They felt that the game failed to capitalize on its potential and didn't offer enough fresh experiences.

#### **4.1.1.9 Doom**

Dark and discolored landscapes are combined with rough, fast-paced gameplay that has made *Doom* famous. The game's catastrophic settings and post-apocalyptic visuals characterize its atmosphere. The landscapes are created with a focus on threatening architecture and ominous lighting to reflect the aggressive and chaotic spirit of the game. An immersive and frightening atmosphere is successfully created by *Doom*'s environmental design to go along with the game's challenging gameplay.

#### **4.1.1.10 Mass Effect 2**

The sci-fi universe of *Mass Effect 2* is vast and varied, and the scenes are brilliantly designed. The game's settings, which range from exotic planets to future cities, are meant to transport players to various spaces and give them a sense of the outside world. Players can explore visually breathtaking regions and fully immerse themselves in the game's massive universe thanks to the attention to detail in the environmental design. *Mass Effect 2* is a visually appealing experience because of the surroundings, which add to the game's overall narrative and atmosphere.

Some users praise the game for its satisfying gameplay, roleplaying elements, and impactful choices that carry over throughout the story. They appreciate the well-written characters and outcomes, considering them superior to those found in games like *Final Fantasy* (Url-14). They appreciate the improved graphics, sound, and voice acting, as well as the continuation of the epic sci-fi storyline. On the other hand, there are users who express disappointment with *Mass Effect 2*. They expected a roleplaying

game with elements similar to the first installment but felt let down by the shift towards a more action-oriented gameplay style.

#### **4.1.1.11 Titanfall 2**

In order to create an original aesthetic, Titanfall 2 combines industrial and futuristic settings. The settings in the game emphasize a sense of power and intensity with their large-scale strikes and dynamic landscapes. The environmental design contrasts organic and mechanical components by using features from both organic and artificial surroundings. The futuristic universe of Titanfall 2 is successfully brought to life by the game's landscapes, which also serve as aesthetically compelling settings for its chaotic action.

#### **4.1.2. Selection process**

These games were studied by the researcher through playing them or by watching gameplay videos on YouTube, focusing on the game's art style and design characteristics. After analyzing the game scenes, specific ones of scenes that could potentially serve as the game's identity were selected for analysis. In addition to possessing identity characteristics, the scenes were chosen based on the presence of measurable 3D asset relationships within the scene. In general, many of the game scenes feature singular, detailed, dominant, and large assets or landscapes. However, while catching the point where these designs are successful, using the 3D composition measurement would not be the right choice, so such scenes were eliminated.

Selection and categorization of 3D assets have been very important for the study as the relationship between 3D assets is examined. Models on a game scene can technically be divided into three: characters, active game elements with which the player interacts, and passive game elements that the player does not interact with, which remain like the background. In this study, while analyzing which model groups should be included in the analysis in order to determine the holistic relationship of the scene in the most accurate way, many studies were examined.

Similarly to this study, Della-Bosca et al. (2017) analyzed game spaces and closely examined their definitions of environment, as they attempted to capture the sense of immersiveness in game spaces. They referenced that pictorial space is the visual representation of the game world, while diegetic space is the interactive space within

that world (Davis, 2004). The authors suggest that the two concepts are crucial to understanding the immersive and interactive nature of certain types of video games.

Although the feature that attracts the actor/spectator includes all the models in the scene, passive elements / pictorial space were chosen for analysis since the flow of the models in motion cannot be taken into account with a singular expression.

## **4.2 Data Categorization**

In Chapter 3, the selection of elements belonging to any given space is expressed through general descriptions, whereas in this chapter, specific elements were chosen as the game environment is selected to be analyzed, leading to more specialized element definitions. In this study, the passive 3D assets known as pictorial space were chosen as the elements. For future studies, skyline, city elements, architectural elements, or horizontal/vertical elements can be selected for the analysis of game scenes.

A 3D asset in the context of video games refers to a 3D object or environment created using computer graphics software. These 3D assets are used in the creation of game environments, characters, and objects, and are designed to provide a sense of depth and realism to the game world. 3D assets are typically created by game artists and designers, who use specialized software such as Maya or Blender to model and texture the objects or environments.

The selection of 3D assets as space elements in this study is based on the fact that they serve as fundamental building blocks that define the game space. In a way, they can be thought of as urban-scale architectural buildings, as they fill the space and establish boundaries within it. By measuring the composition of the space, it was necessary to choose consistent objects that make up the composition as elements. Therefore, 3D assets were selected for their role in defining and shaping the game space, and their contribution to the overall visual composition of the environment.

The 3D game assets used in the given scene are utilized as source objects. The source objects are classified based on whether they are identical to each other or not. In general, a single type of 3D asset is reused in games by positioning it differently, giving rotation, and changing its scale or material, for reasons such as reducing the design time of the game, reducing the load of the game engine, and making the game faster.

The use of the same 3D asset can create a feeling of monotony for the player/audience, and this changes the compositional effect of the space. Therefore, while analyzing source objects, not only the number and location of source objects were taken into account; It was also examined whether they were of the same type (Figure 4.2). Source objects are labeled with letters and if they are the same type, they get the same letter. The source object numbers and expressions of all games are processed in the Excel table (Figure 4.6).



**Figure 4.2:** Classification method of the game assets, ss taken from the game Aion

#### **4.3 Representation: Creating a 3D Scene from a 2D Image**

After the games and scenes were selected and the source objects were classified, the games were transferred to 3 dimensions to analyze. Even though it was possible to analyze the games in the 2D representation of them, using screenshots; 3D representation was preferred as it would be more accurate regarding space relations.

Since the models of the games could not be accessed, they were remodeled. Modeling an exact copy of the models was not considered necessary because it would create a time load for an experimental study and the details of the model would not contribute to the composition measurement. Instead, each model is represented by cubes surrounding it.

In game design, designers place undetailed basic geometries on the game scene using a method called blockout, before detailing and finalizing all models. Using to this

method, designers can see all the models together and evaluate the scene composition subjectively, and when they make a change, they get rid of the time loss caused by detailing the model to be changed. From a similar point of view, using a simple representation method in evaluating the composition of the scenes was seen as an optimized method.

#### Representation methods:

- In order to remodel, 2D screenshots taken from 3D games were used as a reference. Selected games are watched from their gameplay video (A gameplay video is an audiovisual recording of a player's interaction with a video game, typically utilized for entertainment, instructional, or research purposes.)
- The video recordings were set to a resolution of 1080p, and screenshots were taken from there. The computer's graphics card used for taking the screenshots was NVIDIA GeForce GTX 960M. It should be noted that the resolution and color quality of the captured screenshot may affect the results of another study.
- The images were imported into the Maya modeling program, for each game. First of all, the game's original camera settings were tried to be manually transferred to the modeling program for each image. For each file, the camera's focus and perspective angle are set. (This process can be made automatically using AI)
- While the visuals are in a front-orthographic setting, cubes are placed on the assets in the visual. They are rescaled according to the size of the asset in 2D. Wireframe shading style is preferred to do modeling & placing them.
- By taking the camera set to the top and controlling it from the front view, the cubes on the same plane are moved in the 3<sup>rd</sup> dimension to provide a 3d representation in the game (Figure 4.3, Figure 4.4).
- The third dimension of the cubes was rescaled based on the asset's image. The size estimation was made by utilizing the screenshots taken from the game and the author's designer background. Therefore, although the dimensions were represented in an optimized manner, they could not be transferred one-to-one. All models are provided in the appendix, indicating the remodeling phase of all game scenes.
- If there is any slope in the assets used (such as road, bridge), rotation was applied to the representation cubes if it was thought to affect the organization analysis.

Some slopes are either too slight and cannot be clearly discerned from the screenshot, or they are not important in the game flow.

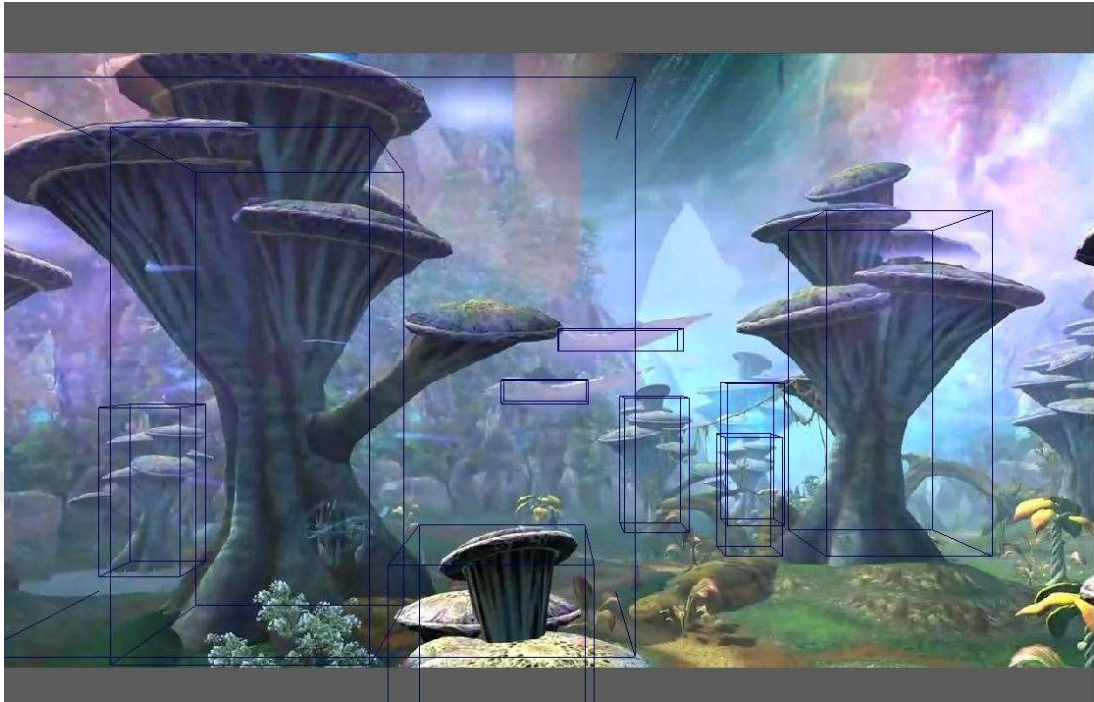


**Figure 4.3:** Representation method of the game assets, screenshot taken from the game Aion.

- After the modeling of all scenes was completed, it was ensured that they were all set to the same scale. Maintaining consistent scales is an important step as disparate scales would render distance measurements incomparable. To achieve this, a cube was modeled to human scale (1.8m x 0.6m x 0.6m) and placed within each scene. The human model was positioned in perspective and scaled to match the scene accurately. In game scenes where the character also appeared, the process was made more practical. The scaling factor of the reference model was recorded and all assets are subsequently divided by this number to equalize the scale of all scenes.
- After the modeling process is finished, the names of the source objects are transferred to the 3D cube models so that the data is not confused in the next stages. If there is more than one source object of the same type, it is left to the user whether to add a second classification tag. For example, if there are 4 source objects of type A, the naming can be made as "A, A, A, A" or "A1, A2, A3, A4".
- In some scenes, landscape elements were considered as one asset; the ground was considered as a single cube. In such cases, since it would not affect the organization and would not be visible in the screenshot, their thickness was kept thin

compared to their other dimensions. If assets such as rock fragments, and trees on the mountain in the background do not have an impact on the game flow and contribute to the visuality with their integrity, they were considered as a single asset rather than as autonomous entities.

- Thus, the selection of which asset set will be considered as a single asset and which ones will be separated is a qualitative decision that forms the basis of the analysis. Automating this process or representing all individual objects within a defined area with clear rules (or using AI) could create a problem of including objects that do not affect the composition of the scene. The best way to understand this is to pay attention to gameplay. In some game sets, a set of objects consisting of detailed and multiple assets is baked into a single simple geometry. The term "bake" refers to dressing the textures/skins of more complex objects onto simpler objects that do not weigh heavily on polygons. Most complex asset sets used in the background are generally based on a single asset and its baked version. In some cases, the walls on the edges of the scene, and the assets in front of the wall are all given in a single object with this method in corridor-like scenes. When using the baking method, attention should be paid to asset categorization. If the designer is going to test his own assets with this method, they should decide whether to test the baked low-geometry asset or the original asset.

Although creating a 3D representation of a 3D space from a 2D image reduced to 2D causes much data loss, it has been the most optimal solution due to data access restrictions. If the study is found useful, this entropy calculation will be more efficient as it will be applied to the designer's block-out models that are in the early design stage. In addition, since this study is proof of a concept, it is considered sufficient to create data manually, although it is not ideal. The suggestion for future studies is to make the selection and representation of these assets with the help of artificial intelligence if a 3D scene is to be prepared from 2D visuals. With the Image recognition method, assets can be separated and their dimensions can be calculated and represented by a cube or a basic geometry.

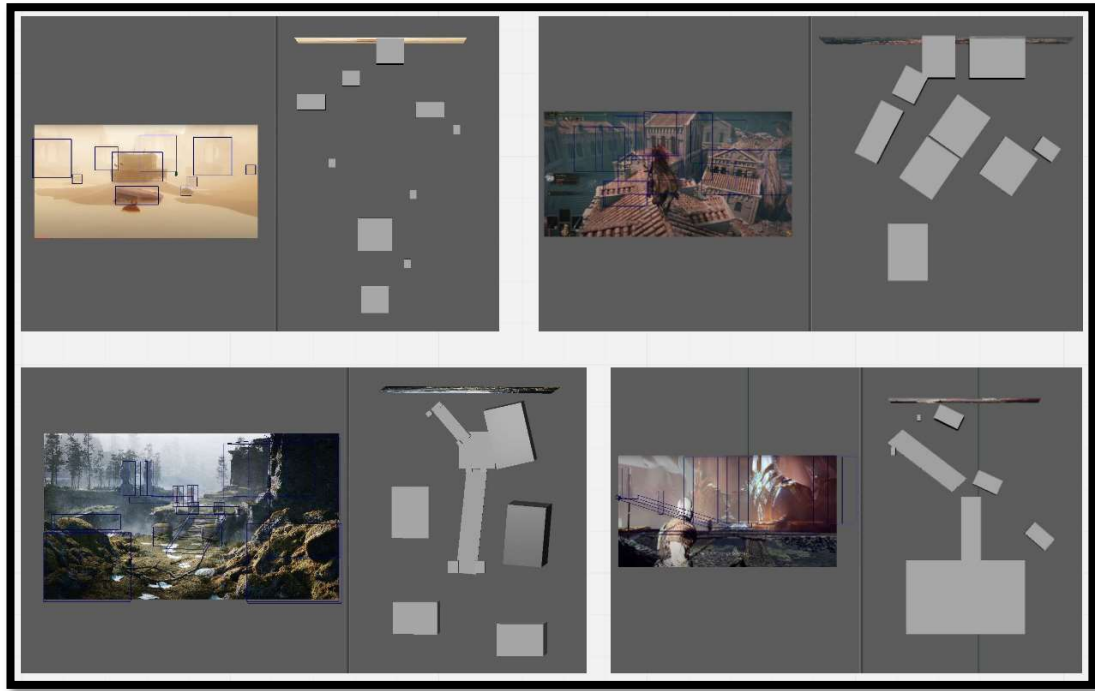


**Figure 4.4:** Remodeling phase of the game scenes, all game scene are provided at the appendix.

#### 4.4 Proximity Calculations for the Source Objects

After the representations and object classifications were made for the composition, the calculation of relationships between source objects is performed. The calculation process can be listed as follows:

- The 3D representations obtained in the study were transferred to the Rhinoceros 3D program. The cubes modeled in the Maya program are exported in a way that their scale and positions will not change and are imported into Rhinoceros 3D program. In order to transfer the data of these cubes to the Grasshopper tool, which works as a plug-in in the Rhinoceros 3D program, the type of the models must be changed first. The purpose of this change is to enable Grasshopper to pull data from these models. Meshes created in the Maya program are defined as "closed mesh" in Rhinoceros. By selecting all meshes and applying the "MeshToNURB" command, the meshes are converted to the "closed solid polysurface" type.
- After the data becomes readable by Grasshopper, it is transferred to the scripting previously created by the author in Grasshopper. The script in Grasshopper receives separate data for each geometry (Figure 4.5). In order to assign cube models to the previously created empty "Geometry" parameters, a cube model must be

selected in the Rhinoceros window, the parameter must be clicked on in the Grasshopper window, and the “Set one Geometry” command must be clicked. The important thing here is to assign the source objects in order from top to bottom. The working logic of the code accepts the first geometry as the first source object. The user can change the name of the Grasshopper parameter after assigning the geometry to avoid confusion in the future. The name information of the previously named 3D cube models in the Maya program can be found on the right side of the Rhinoceros window, under the "Properties" heading.

- After the data of the geometries are transferred to the relevant parameters, the geometry names in the Grasshopper C# script should be revised according to the source object labels. If the first object is defined as A, the second as B, and the third as B, the names should be changed in this way in the sorted list. With the determination of source object names, the previously written Grasshopper C# script immediately outputs the distances between all source objects and source object names as a result.
- The output data from the Grasshopper are translated into an Excel database, while the category and the labels of the source objects are determined. The proximity among the source objects is assigned as relationship type parameters (RTP). In other words, the source objects and distances established between them in the environment are divided into categories based on their types. All RTP values gathered from the scenes emerged in a list. And they are limited to 3 main classes: close(X), medium(Y), and far(Z).
- With the usage of “meshVolume” component in the Grasshopper, object volumes are also gathered and transferred to the Excel file.
- The entropy value of the overall scene is calculated through the sum of individual calculations by using RTP and Shannon’s entropy formula (1948).

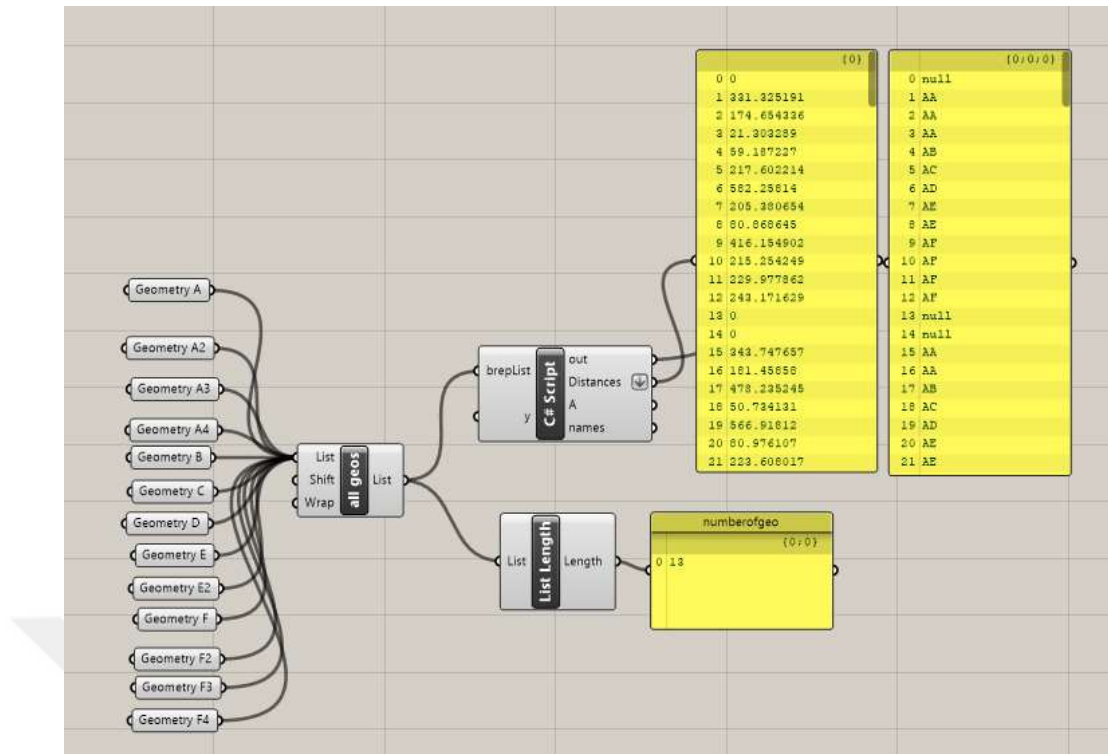


**Figure 4.5:** Calculating the distances between the source objects, using Grasshopper.

#### 4.4.1 The Grasshopper script

Grasshopper is a powerful plugin for Rhino that enables users to create complex geometric shapes and structures using a visual programming language. It allows users to create and manipulate 3D geometry, animations, and parametric designs by visually connecting components together in a flowchart-style interface.

The author used Grasshopper visual scripting components in order to calculate proximity between source objects. “all go” component collects all geometries’ data as a list. Their collected data is transferred to a special C# script written in the Grasshopper by the author.

- The C# script collects the centers of the objects it receives data from in a list. It sequentially calculates the closest points of object (i) and object (i+1) to each other, then measures the distance between them. To go into detail;
- Script firstly calculates the closest point on the surface of the object (i +1) to the center of the object (i), named the list “B”.
- Then calculates the closest point on the surface of the object (i +1) to B, named the list “selfPoint”.

- The distance between “B” and “selfPoint” gives the distance between two objects in 3D.
- While calculating all distances with a loop, every loop takes the distance and the names of the objects to different lists. Users can access the final lists immediately.

#### 4.5 Entropy Calculation

The data from Grasshopper provides the distance between each source object and its consecutive objects, as well as their names, given as separate outputs. These data are organized in Excel. Due to the code structure, this data is received separately, but the code can be developed or customized for future similar measurements.

- As shown in Figure 4.6, an Excel table was prepared for each scene. The tables for all scenes are available in the appendix.

Distance data of 1187 points has been obtained. Various methods have been tried to divide these distances into 3 groups. It has been observed that there is a significant accumulation in the range of 0-25M, with only one element having a value of 100M and 19 elements being greater than 50M. When classification is done based on the taking range method, the majority of the classifications result in 'X' due to the clustering at one end of the data. The reason for this could be the lack of identification of background assets or the unsuccessful conveyance of perspective. As a solution, the percentile cutoff, namely the 19 elements outside the range calculation, has been excluded in order for the classification to group different elements more optimally. The data has been divided into three intervals based on ranges: 0-17M is classified as 'X', 17M-34M is classified as 'Y', and values greater than 33M are classified as 'Z'.

Although the modeled cubes are consistent with each other in terms of scale, they have been modeled visually, independent of units such as meters or centimeters. Therefore, the distances between assets and the volumes of objects are left unitless (Can be seen in Figure 4.6). They are all consistent with each other in their relationships, which is necessary for entropy calculation.

When parsing distance data, the interval ranges were determined by adding one-third of the difference between the maximum and minimum values. Different parsing methods can be selected according to the researcher's preference in future studies.

- Distance measurements recorded in Excel are classified into three groups: X, Y, and Z, generating relationship type parameters (RTP). As all scenes scaled accordingly with each other, their RTP values were calculated together. For future studies, it can be calculated separately for each scene (It is not suggested as they will not be comparable).
- RTPs and their respective source object labels are combined to obtain the Overall Object-Proximity Relationship parameter (OOPR), such as AAZ, BBY, etc. (Figure 4.6).
- The diversity of UOPR, which is the special connection established between source objects, varies depending on the distribution of the distance types between the same/different types of elements of source objects. The number of OOPRs is constant within a scene, while the diversity changes. For example, in the set of relationships AAX, AAX, and AFX, the number of OOPR is 3, and the number of UOPR is 2.
- Entropy calculation is performed between OOPR and UOPR numbers. Dividing the UOPR value by the OOPR value represents the "p" symbol in the entropy formula (2), which is the fundamental calculation measuring the scene's uncertainty.

$$H = - \sum_{i=1}^{n \text{ level}} p_i \log_2 p_i . \quad (2)$$

$$p = (\text{UOPR} / \text{OOPR})$$

After calculating the entropies of all scenes, the data was transferred to another table (Table 4.1). In this table, entropy values gathered in the study are compared with several datasets, including the element count, element type count, OOPR, UOPR, success ratings of the games (The Metacritic scores 1 and 2), Distance Frequency, Distance Observation, Object Volume Observation, Object Volume Frequency, and Object Volume Graph. The Metacritic scores were accessed on June 10, 2023.

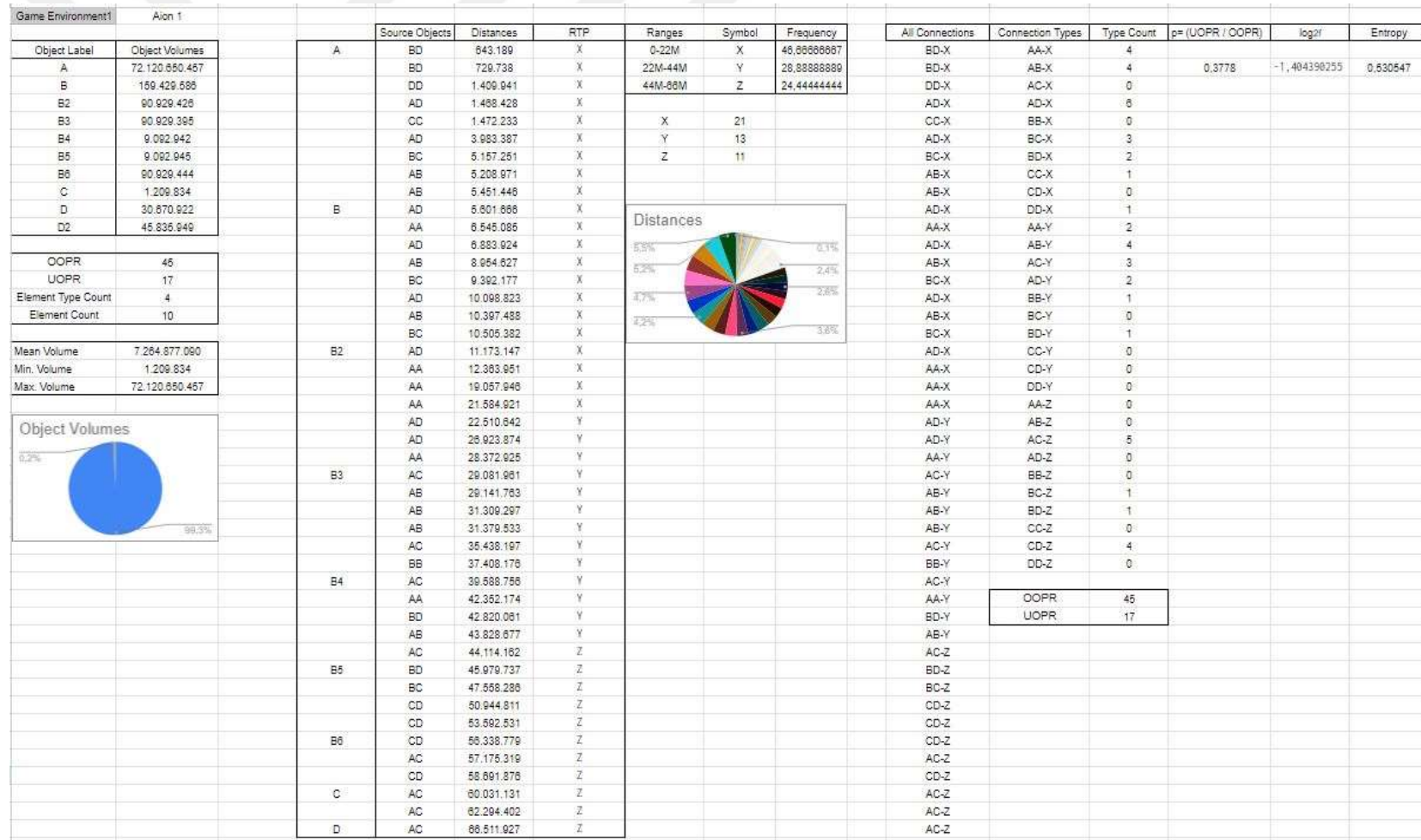


**Figure 4.6:** The figure shows the entropy calculation performed for the game scene Ghost of Tsushima. The tables for all scenes are provided in the appendix.

Data sets of the element count, element type count, OOPR, and UOPR are used for the entropy calculation. If these data are compared with entropy, the coherent relationship between the total number of elements and the number of element types in a scene can be observed. On Metacritic, there are two types of scores. One is obtained from all players and users (User score), while the other is calculated based on ratings from expert reviewers referred to as "Critic Reviews/ Metascore" on the website. In the study, both scores are included in the comparison table because there is a significant difference between these two scores in some of the sampled games.

Distance Frequency and Distance Observation have been added to the table in order to interpret the distance between assets qualitatively and quantitatively. The classifications of distances as X, Y, and Z have been calculated as percentages, and the percentage calculation of the X class has been included in the table as Frequency. This allows us to interpret a high presence of the X class (sometimes 100%) as clustering among the assets. The Observation section represents the interpreted form of this data as either "Homogeneous" or "Clustering" effects.

The headings Object Volume Observation, Object Volume Frequency, and Object Volume Graph have been added to interpret the effect of asset sizes on scene composition qualitatively and quantitatively. A pie chart of the sizes of all objects in the scene has been created, and the Object Volume Graph has been compiled under the Data set. The highest percentage in the graph, representing the object with the largest volume, is quantified as Object Volume Frequency. Frequency is then observed using the terms "Dominance" and "Homogeneous" to create the Object Volume Observation column. Objects with very large volumes have a dominating effect and influence the composition.

From the table presented in Figure 4.7, a multiple linear regression was applied by creating a new table (Table 4.1) with selected columns (Element Count, Element Type Count, Distance Frequency, Object Volume Frequency, Metacritic Score2). The quantities OOPR and UOPR, which directly influence the calculation of entropy, were not included in the table. Only one of the Metacritic scores was chosen as predictor variables. In Table 4.1, entropy was attempted to be negated using the other data (Element Count, Element Type Count, Distance Frequency, Object Volume Frequency, Metacritic Score2 ) and was estimated with a very low margin of error (Table 4.2).

## 4.6 Findings

When examining the entropy values in the table, it can be observed that most scenes received similar scores. With the exception of the Destiny 2\_2 scene, where the score is 0,11, the remaining scores can be considered close to each other. To evaluate the effectiveness of the Entropy method in calculating the composition of 3D spaces, the entropy results are compared with various features.

- The reason for performing the regression analysis is to estimate the dependent measure (entropy) from a set of independent measures, obtained in the study. Regression is done to find out which measures significantly estimate the Entropy and also how important predict the Entropy value. In this calculation, the relations between entropy results and other predictor has been determined (Table 4.2). The Multiple R-value provides the correlation between the predictor variables and the Entropy variable. The multiple correlation between the Entropy variable and the predictor variables was found as 0.781501839 which means that 61% of the variance in the Entropy variable can be explained due to changes in predictor variables. The estimation error was found to be 0.067566312. And multiple regression equation was found to be significant ( $p=0,005901695$ ), which is close to 0.05. So, the predictor variables can be used to estimate Entropy values (Table 4.2). Most effective predictor is found as the “Element Count Type” variable to estimate Entropy value.
- Table 4.1 shows some multiple regression statistics to predict the entropy value. In the end, it can be observed that the difference between the predicted entropy values from the regression and the actual entropy values is very small. When the absolute values of all differences are taken and averaged, it appears that the mean absolute difference is estimated as 0.04, which also shows the validity of Entropy estimates from predictor variables by using a multiple regression approach.

|            | Game Name& Scene               | Entropy  | Element Count | Element Type Count | OOPR | UOPR | Metacritic Score1 | Metacritic Score2 | Distance FrequencyX | Distance Observation | Object Volume Observation | Object Volume Frequency | Object Volume Graph                                                                   |
|------------|--------------------------------|----------|---------------|--------------------|------|------|-------------------|-------------------|---------------------|----------------------|---------------------------|-------------------------|---------------------------------------------------------------------------------------|
| entropy_7  | Elden Ring 1                   | 0.530647 | 9             | 5                  | 36   | 13   | 7.8               | 96                | 100                 | Clustering           | Homogenous                | 28                      |    |
| entropy_1  | Aion 1                         | 0.528771 | 10            | 4                  | 45   | 18   | 6.6               | 76                | 42                  | Homogenous           | Dominance                 | 99                      |    |
| entropy_2  | God of War 4_1                 | 0.529652 | 16            | 7                  | 120  | 47   | 9.1               | 94                | 62                  | Clustering           | Dominance                 | 36                      |    |
| entropy_11 | Star Wars Jedi: Fallen Order_1 | 0.528321 | 9             | 6                  | 36   | 12   | 7.6               | 79                | 100                 | Clustering           | Dominance                 | 34                      |    |
| entropy_8  | Elden Ring 2                   | 0.500000 | 9             | 6                  | 36   | 18   | 7.8               | 96                | 100                 | Clustering           | Homogenous                | 28                      |    |
| entropy_10 | Ghost Of Tsushima 2            | 0.503455 | 13            | 6                  | 78   | 20   | 9.1               | 83                | 96                  | Clustering           | Dominance                 | 73                      |    |
| entropy_6  | God of War 4_2                 | 0.461346 | 8             | 5                  | 28   | 16   | 9.1               | 94                | 64                  | Clustering           | Dominance                 | 33                      |    |
| entropy_5  | Journey 2                      | 0.496814 | 10            | 4                  | 45   | 11   | 8.3               | 92                | 82                  | Clustering           | Homogenous                | 28                      |   |
| entropy_4  | Journey 1                      | 0.453604 | 9             | 7                  | 36   | 21   | 8.3               | 92                | 86                  | Clustering           | Dominance                 | 69                      |  |
| entropy_3  | Aion 2                         | 0.441618 | 17            | 7                  | 136  | 24   | 6.6               | 76                | 100                 | Clustering           | Homogenous                | 26                      |  |

**Figure 4.7.** All conclusions.

|            |                                |          |    |   |    |    |     |    |     |            |            |    |  |
|------------|--------------------------------|----------|----|---|----|----|-----|----|-----|------------|------------|----|--|
| entropy_9  | Ghost Of Tsushima 1            | 0.389975 | 7  | 6 | 21 | 14 | 9.1 | 83 | 86  | Clustering | Dominance  | 61 |  |
| entropy_12 | Star Wars Jedi: Fallen Order_2 | 0.328137 | 6  | 6 | 15 | 11 | 7.6 | 79 | 100 | Clustering | Homogenous | 26 |  |
| entropy_13 | Control 1                      | 0.528771 | 11 | 5 | 55 | 22 | 7.4 | 82 | 40  | Homogenous | Dominance  | 37 |  |
| entropy_14 | Control 2                      | 0.461346 | 8  | 5 | 28 | 16 | 7.4 | 82 | 75  | Clustering | Dominance  | 61 |  |
| entropy_15 | Destiny2_1                     | 0.400212 | 11 | 7 | 55 | 36 | 5.0 | 85 | 33  | Homogenous | Dominance  | 60 |  |
| entropy_16 | Destiny2_2                     | 0.115070 | 9  | 8 | 36 | 33 | 5.0 | 85 | 64  | Clustering | Dominance  | 37 |  |
| entropy_17 | Doom 1                         | 0.476983 | 11 | 7 | 55 | 30 | 8.4 | 85 | 73  | Clustering | Homogenous | 21 |  |
| entropy_18 | Doom 2                         | 0.522064 | 11 | 5 | 55 | 24 | 8.4 | 85 | 62  | Clustering | Homogenous | 36 |  |
| entropy_19 | Mass Effect2_1                 | 0.516387 | 14 | 6 | 91 | 26 | 8.9 | 94 | 85  | Clustering | Dominance  | 60 |  |
| entropy_20 | Mass Effect2_2                 | 0.402721 | 12 | 8 | 66 | 43 | 8.9 | 94 | 71  | Clustering | Homogenous | 25 |  |
| entropy_21 | Titanfall2_1                   | 0.453604 | 9  | 6 | 36 | 21 | 8.6 | 89 | 83  | Clustering | Homogenous | 18 |  |
| entropy_22 | Titanfall2_2                   | 0.515017 | 13 | 5 | 78 | 22 | 8.6 | 89 | 63  | Clustering | Homogenous | 10 |  |

**Figure 4.7. (continued) All conclusions.**

**Table 4.1.** Regression calculations.

| Entropy    | Game Name<br>& Scene              | Element Count | Element Type<br>Count | Distance<br>Frequency | Object Volume<br>Frequency | Metacritic<br>Score2 | Entropy  | Predicted<br>Entropy | Differences |
|------------|-----------------------------------|---------------|-----------------------|-----------------------|----------------------------|----------------------|----------|----------------------|-------------|
| entropy_7  | Elden Ring 1                      | 9             | 5                     | 100                   | 28                         | 96                   | 0,530647 | 0,5288330            | 0,00181391  |
| entropy_1  | Aion 1                            | 10            | 4                     | 42                    | 99                         | 76                   | 0,528771 | 0,5317901            | -0,0030191  |
| entropy_2  | God of War 4_1                    | 16            | 7                     | 62                    | 36                         | 94                   | 0,529652 | 0,5014221            | 0,02822981  |
| entropy_11 | Star Wars Jedi: Fallen<br>Order_1 | 9             | 6                     | 100                   | 34                         | 79                   | 0,528321 | 0,4186778            | 0,10964316  |
| entropy_8  | Elden Ring 2                      | 9             | 6                     | 100                   | 28                         | 96                   | 0,5      | 0,4694250            | 0,03057495  |
| entropy_10 | Ghost Of Tsushima 2               | 13            | 6                     | 96                    | 73                         | 83                   | 0,503455 | 0,5143700            | -0,0109150  |
| entropy_6  | God of War 4_2                    | 8             | 5                     | 64                    | 33                         | 94                   | 0,461346 | 0,4815944            | -0,0202484  |
| entropy_5  | Journey 2                         | 10            | 4                     | 82                    | 28                         | 92                   | 0,496814 | 0,5800133            | -0,0831993  |
| entropy_4  | Journey 1                         | 9             | 7                     | 86                    | 69                         | 92                   | 0,453604 | 0,4051069            | 0,04849706  |
| entropy_3  | Aion 2                            | 17            | 7                     | 100                   | 26                         | 76                   | 0,441618 | 0,4870689            | -0,0454509  |

**Table 4.1. (continued)** Regression calculations.

| Entropy    | Game Name<br>& Scene           | Element Count | Element Type<br>Count | Distance<br>Frequency | Object Volume<br>Frequency | Metacritic<br>Score2 | Entropy  | Predicted<br>Entropy | Differences |
|------------|--------------------------------|---------------|-----------------------|-----------------------|----------------------------|----------------------|----------|----------------------|-------------|
| entropy_9  | Ghost Of Tsushima 1            | 7             | 6                     | 86                    | 61                         | 83                   | 0,389975 | 0,3981281            | -0,0081531  |
| entropy_12 | Star Wars Jedi: Fallen Order_2 | 6             | 6                     | 100                   | 26                         | 79                   | 0,328137 | 0,3632699            | -0,0351329  |
| entropy_13 | Control 1                      | 11            | 5                     | 40                    | 37                         | 82                   | 0,528771 | 0,4805254            | 0,04824555  |
| entropy_14 | Control 2                      | 8             | 5                     | 75                    | 61                         | 82                   | 0,461346 | 0,4637949            | -0,0024489  |
| entropy_15 | Destiny2_1                     | 11            | 7                     | 33                    | 60                         | 85                   | 0,400212 | 0,3761272            | 0,02408474  |
| entropy_16 | Destiny2_2                     | 9             | 8                     | 64                    | 37                         | 85                   | 0,11507  | 0,292631             | -0,1775612  |
| entropy_17 | Doom 1                         | 11            | 7                     | 73                    | 21                         | 85                   | 0,476983 | 0,3879885            | 0,08899441  |
| entropy_18 | Doom 2                         | 11            | 5                     | 62                    | 36                         | 85                   | 0,522064 | 0,5052094            | 0,01685456  |
| entropy_19 | Mass Effect2_1                 | 14            | 6                     | 85                    | 60                         | 94                   | 0,516387 | 0,5527808            | -0,0363938  |
| entropy_20 | Mass Effect2_2                 | 12            | 8                     | 71                    | 25                         | 94                   | 0,402721 | 0,3727020            | 0,0300189   |
| entropy_21 | Titanfall2_1                   | 9             | 6                     | 83                    | 18                         | 89                   | 0,453604 | 0,4310577            | 0,02254622  |
| entropy_22 | Titanfall2_2                   | 13            | 5                     | 63                    | 10                         | 89                   | 0,515017 | 0,5419971            | -0,0269801  |

**Table 4.2.** Regression Statistics

| Regression Statistics |             |
|-----------------------|-------------|
| Multiple R            | 0,781501839 |
| R-Squared             | 0,610745124 |
| Adjusted R-Squared    | 0,489102975 |
| Standard Error        | 0,067566312 |
| Observations          | 22          |
| Significance F        | 0,005901695 |

- When comparing the number of elements (source objects) and the number of element types with entropy, it is generally observed that as the number of elements decreases, the entropy also decreases.
- Since the selected games are known for receiving high scores and being considered successful in different lists and sources, it is expected that their calculated entropy values are similar, too. Most of the entropy values of the scenes are found similar to the Metacritic scores.
- Destiny 2\_2 scene is take the lowest score both from Entropy and Metacritic.



## 5. CONCLUSION & FUTURE STUDIES

There is a desire to develop a control and analysis method that can assist in virtual space design due to the increasing presence of virtual spaces in human life. The term virtual space is examined to understand how the concept of space is approached, which features are analyzed, and the representation techniques used. The literature was classified into Space Type, Space Aspect, Analyze Method, Space Element, and Representation Technique. It was observed that the analysis of virtual spaces predominantly focuses on representing and analyzing game environments in 3D models. In this study, existing game designs were selected for analysis, specifically focusing on RPG, science-fiction, and fantasy genres. The reason for this selection was the expectation that these games would provide abundant data for exploring design decisions in virtual environments.

There are numerous studies that examine different types and elements of spatial design using various methods at different scales. However, this study takes a unique approach by focusing on games as a visual space and representing them in the third dimension, unlike many other studies. Previous research on games often focuses on their playability and involves subjective evaluations, whereas this study utilizes objective measurement procedures to measure entropy as an assessment tool.

Screenshots of the selected games were captured as 2D frames, and these images were used to create 3D models representing the scenes. The game models were reconstructed since direct access to the original 3D models was not possible. Each game asset in the image was represented by a cube model with exact dimensions matching the asset.

The distances between the 3D models, the names of the models creating those distances, and the volumes of the models were calculated and recorded in an Excel spreadsheet. Based on these results, parameters such as RTP, OOPR, and UOPR were computed, and entropy values were determined. Entropy is selected among other measurement methods as it gets the diversity.

By interpreting the results of the analysis in the study to assess the effectiveness of the entropy method in measuring spatial composition, it can be observed that the entropy values of the analyzed scenes correspond to the success scores of the games and the descriptive qualities of the scenes. In this regard, it is recommended to further develop the analysis method tested in the study and utilize it in spatial design.

The desired model will take an image file as input, it will automatically identify assets and calculate entropy values for the assets based on the proximity relationships and the repetition frequencies of the objects in the whole.

This study, it is aimed to propose a tool and method that can be used by designers and researchers who are interested in space, virtual space, design, and game environment design. Any designer using a 3D modeling program can measure the entropy of their models in the scene with the help of the script produced in this study; especially when they prepare their scene with the block-out method (placing models without details). According to the entropy result, they can interpret their scene and change the distances between the assets, or the variety and size of the assets.

On the other hand, any theoretical researcher working on space design can examine the classification of the space according to its aspects discussed in the literature and can observe the use of space in the design. In Chapter 3, a systematic table focusing on the classification of space can be found. Also, the table can help researchers who work on space features such as aesthetics, complexity, and visibility, or who aim to analyze space with methods such as entropy and fractality, or who will represent the space.

In Chapter 4, a detailed layout of the techniques employed in the study is provided. It should be noted that alternative techniques and methods could have been used, potentially leading to different outcomes. Limitations in the study can be given as:

- Selected virtual space type
- Selected games, genres, and scenes
- Number of games and scenes examined
- Classification of the elements
- Representation method
- Manually selection of the elements and scenes

- Manually remodeling the scenes
- Using a unique script for proximity calculation
- Measuring entropy
- Measuring proximity

In the event of further development of this study, alternative games could be selected instead of the ones chosen as examples. Other genres could be explored, or different scenes within the same games could be selected. The accuracy of the analysis can be enhanced with a larger sample size; thus it is recommended to conduct further scene analyses for the continuation of this study. Building upon the methodology presented in Chapter 3, any space other than the game environment can be analyzed.

In this study, a single frame was taken as a reference from each game, and analyses were conducted based on these frames. However, if multiple frames or a sequence of movie frames had been selected instead of a single frame, the perception and representation of the space, as well as the analysis outcomes, could have been different. In the case of representing the space with multiple frames, dynamic elements that were not captured in a single image could be incorporated into the analysis, or the flow of dynamic elements captured throughout the images could add a different nuance to the study.

To further elaborate on the frequent mention of the use of artificial intelligence (AI) throughout the study, AI can be applied in various aspects. The process of transitioning 2D game scenes to 3D was carried out manually. All game elements were represented by bounding boxes in accordance with their visual boundaries, and these boxes were modeled. In order to make the selection and representation of game elements more objective and precise, it is recommended to employ AI methods in future studies. The ADE20K dataset contains trained data that can include game elements. These datasets can be utilized to compare game scenes and segment objects using segmentation methods, allowing for their labeling. The boundaries of the objects can be selected and represented by 2D bounding boxes. Once this process is standardized, adding depth to the visuals can be achieved manually but in a more efficient manner (Url-03, Url-04).

On the other hand, the manual selection of visuals and the manual categorization of assets in the study contribute to its autonomy. The researcher's background in

architecture and game design brings a certain uniqueness to the selection process based on this cognitive background. The researcher has been able to identify assets that may have different sizes, rotations, or positions if they appear the same, but contemporary AI technology would likely classify them differently. The architectural background facilitates the interpretation of 2D images into 3D, at least in the present time when the AI applications' perception of 2D to 3D may be weaker.

Many methods have been used to analyze the space. As an alternative to using the entropy method, one of the objective measurement methods could have been used, such as fractality, space syntax, and fuzzy logic.

The answers to the research questions of this study can be given as:

The entropy method makes abstract properties measurable through diversity. Due to this feature, certain aspects of virtual spaces have been measured with entropy in many studies. In order to measure the success, aesthetics, and diversity of the space, the elements that create these features are converted into data, and their entropies are calculated. In this study, which proposes a new measurement tool, it is desired to measure the composition aspects of the game environments, and the distances and assets are chosen as the elements that create the composition. The numerical data of these elements were calculated with entropy measurement and gave information about a certain feature of the selected virtual space by measuring it.

In today's world, designers can understand the success of their designs by interpreting user feedback after presenting their products to users. Having a method to evaluate their designs during the early stages can save a lot of time and effort, and it can also define the virtual space from a specific perspective. In this study, the proposed tool provides significant feedback to the designer by measuring the composition of the virtual space using the entropy method. The designer can transfer the modeled assets to the Grasshopper program and learn about the entropy of the scene using the provided script. They can compare the obtained entropy values with the entropy ranges from the study or determine their own ideal entropy range. To determine the ideal entropy range, the designer should repeat the steps in this study to define ideal virtual scenes, select their elements, represent them in 3D, and transfer them using the provided script. They can compare each obtained entropy result with their own scene.

In this study, the entropy values of selected game scenes were compared with the game ratings received from users. Based on the comparison, it can be said that they obtained similar values and there is a relationship between them.

As a result of this study, it is concluded that there is a need for a measurement method for the evaluation of virtual spaces. In order to respond to this need, a measurement tool established with the entropy method for analyzing existing spaces has been proposed. Among the accessible virtual spaces, an analysis of game spaces is proposed in terms of the number of access to the user mass.





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## **APPENDICES**

**APPENDIX A:** Entropy Calculations of the scenes.

**APPENDIX B:** Representing & remodeling process of the games.



## APPENDIX A: Entropy Calculations of the scenes.

| Game Environment1  |                | Aion 1 |    |                |            |         |        |        |             |  |  |                 |                  |            |                  |              |          |  |
|--------------------|----------------|--------|----|----------------|------------|---------|--------|--------|-------------|--|--|-----------------|------------------|------------|------------------|--------------|----------|--|
|                    |                |        |    | Source Objects | Distances  | RTP     | Ranges | Symbol | Frequency   |  |  | All Connections | Connection Types | Type Count | p= (UOPR / OOPR) | log2f        | Entropy  |  |
| Object Label       | Object Volumes | A      | BD | 643.189        | X          | <17M    | X      |        | 42,22222222 |  |  | BD-X            | AA-X             | 2          |                  |              |          |  |
| A                  | 72.120.650.457 |        | BD | 729.738        | X          | 17M-34M | Y      |        | 20          |  |  | BD-X            | AB-X             | 4          | 0,4000           | -1,321928095 | 0,528771 |  |
| B                  | 159.429.586    |        | DD | 1.409.941      | X          | >34M    | Z      |        | 37,77777778 |  |  | DD-X            | AC-X             | 0          |                  |              |          |  |
| B2                 | 90.929.426     |        | AD | 1.468.428      | X          |         |        |        |             |  |  | AD-X            | AD-X             | 6          |                  |              |          |  |
| B3                 | 90.929.395     |        | CC | 1.472.233      | X          | X       | 19     |        |             |  |  | CC-X            | BB-X             | 0          |                  |              |          |  |
| B4                 | 9.092.942      |        | AD | 3.983.387      | X          | Y       | 9      |        |             |  |  | AD-X            | BC-X             | 3          |                  |              |          |  |
| B5                 | 9.092.945      |        | BC | 5.157.251      | X          | Z       | 17     |        |             |  |  | BC-X            | BD-X             | 2          |                  |              |          |  |
| B6                 | 90.929.444     |        | AB | 5.208.971      | X          |         |        |        |             |  |  | AB-X            | CC-X             | 1          |                  |              |          |  |
| C                  | 1.209.834      |        | AB | 5.451.446      | X          |         |        |        |             |  |  | AB-X            | CD-X             | 0          |                  |              |          |  |
| D                  | 30.670.922     |        | AD | 5.601.666      | X          |         |        |        |             |  |  | AD-X            | DD-X             | 1          |                  |              |          |  |
| D2                 | 45.835.949     | B      | AA | 6.545.085      | X          |         |        |        |             |  |  | AA-X            | AA-Y             | 3          |                  |              |          |  |
|                    |                |        | AD | 6.883.924      | X          |         |        |        |             |  |  | AD-X            | AB-Y             | 3          |                  |              |          |  |
| OOPR               | 45             |        | AB | 8.954.627      | X          |         |        |        |             |  |  | AB-X            | AC-Y             | 1          |                  |              |          |  |
| UOPR               | 18             |        | BC | 9.392.177      | X          |         |        |        |             |  |  | BC-X            | AD-Y             | 2          |                  |              |          |  |
| Element Type Count | 4              |        | AD | 10.098.823     | X          |         |        |        |             |  |  | AD-X            | BB-Y             | 0          |                  |              |          |  |
| Element Count      | 10             |        | AB | 10.397.488     | X          |         |        |        |             |  |  | AB-X            | BC-Y             | 0          |                  |              |          |  |
|                    |                |        | BC | 10.505.382     | X          |         |        |        |             |  |  | BC-X            | BD-Y             | 0          |                  |              |          |  |
| Mean Volume        | 7.264.877.090  |        | B2 | AD             | 11.173.147 | X       |        |        |             |  |  |                 | AD-X             | CC-Y       | 0                |              |          |  |
| Min. Volume        | 1.209.834      |        |    | AA             | 12.363.951 | X       |        |        |             |  |  |                 | AA-X             | CD-Y       | 0                |              |          |  |
| Max. Volume        | 72.120.650.457 |        |    | AA             | 19.057.946 | Y       |        |        |             |  |  |                 | AA-Y             | DD-Y       | 0                |              |          |  |
|                    |                | AA     |    | 21.584.921     | Y          |         |        |        |             |  |  | AA-Y            | AA-Z             | 1          |                  |              |          |  |
|                    |                | AD     |    | 22.510.642     | Y          |         |        |        |             |  |  | AD-Y            | AB-Z             | 1          |                  |              |          |  |
|                    |                | AD     |    | 26.923.874     | Y          |         |        |        |             |  |  | AD-Y            | AC-Z             | 7          |                  |              |          |  |
|                    |                | AA     |    | 28.372.925     | Y          |         |        |        |             |  |  | AA-Y            | AD-Z             | 0          |                  |              |          |  |
|                    |                | AC     |    | 29.081.961     | Y          |         |        |        |             |  |  | AC-Y            | BB-Z             | 1          |                  |              |          |  |
|                    |                | AB     |    | 29.141.763     | Y          |         |        |        |             |  |  | AB-Y            | BC-Z             | 1          |                  |              |          |  |
|                    |                | AB     |    | 31.309.297     | Y          |         |        |        |             |  |  | AB-Y            | BD-Z             | 2          |                  |              |          |  |
|                    |                | B3     | AB | 31.379.533     | Y          |         |        |        |             |  |  | AB-Y            | CC-Z             | 0          |                  |              |          |  |
|                    |                |        | AC | 35.438.197     | Z          |         |        |        |             |  |  | AC-Z            | CD-Z             | 4          |                  |              |          |  |
|                    |                |        | BB | 37.408.176     | Z          |         |        |        |             |  |  | BB-Z            | DD-Z             | 0          |                  |              |          |  |
|                    |                |        | AC | 39.588.756     | Z          |         |        |        |             |  |  | AC-Z            |                  |            |                  |              |          |  |
|                    |                |        | AA | 42.352.174     | Z          |         |        |        |             |  |  | AA-Z            | OOPR             | 45         |                  |              |          |  |
|                    |                |        | BD | 42.820.061     | Z          |         |        |        |             |  |  | BD-Z            | UOPR             | 18         |                  |              |          |  |
|                    |                |        | AB | 43.828.677     | Z          |         |        |        |             |  |  | AB-Z            |                  |            |                  |              |          |  |
|                    |                |        | AC | 44.114.162     | Z          |         |        |        |             |  |  | AC-Z            |                  |            |                  |              |          |  |
|                    |                |        | BD | 45.979.737     | Z          |         |        |        |             |  |  | BD-Z            |                  |            |                  |              |          |  |
|                    |                |        | B4 |                |            |         |        |        |             |  |  |                 |                  |            |                  |              |          |  |
|                    |                |        |    |                |            |         |        |        |             |  |  |                 |                  |            |                  |              |          |  |
|                    |                |        |    |                |            |         |        |        |             |  |  |                 |                  |            |                  |              |          |  |
|                    |                |        |    |                |            |         |        |        |             |  |  |                 |                  |            |                  |              |          |  |
|                    |                |        |    |                |            |         |        |        |             |  |  |                 |                  |            |                  |              |          |  |
|                    |                |        |    |                |            |         |        |        |             |  |  |                 |                  |            |                  |              |          |  |
|                    |                |        |    |                |            |         |        |        |             |  |  |                 |                  |            |                  |              |          |  |
|                    |                |        |    |                |            |         |        |        |             |  |  |                 |                  |            |                  |              |          |  |
|                    |                |        |    |                |            |         |        |        |             |  |  |                 |                  |            |                  |              |          |  |
|                    |                |        |    |                |            |         |        |        |             |  |  |                 |                  |            |                  |              |          |  |
|                    |                | B5     |    |                |            |         |        |        |             |  |  |                 |                  |            |                  |              |          |  |
|                    |                |        |    |                |            |         |        |        |             |  |  |                 |                  |            |                  |              |          |  |
|                    |                |        |    |                |            |         |        |        |             |  |  |                 |                  |            |                  |              |          |  |
|                    |                |        |    |                |            |         |        |        |             |  |  |                 |                  |            |                  |              |          |  |
|                    |                |        |    |                |            |         |        |        |             |  |  |                 |                  |            |                  |              |          |  |
|                    |                |        |    |                |            |         |        |        |             |  |  |                 |                  |            |                  |              |          |  |
|                    |                |        |    |                |            |         |        |        |             |  |  |                 |                  |            |                  |              |          |  |
|                    |                |        |    |                |            |         |        |        |             |  |  |                 |                  |            |                  |              |          |  |
|                    |                |        |    |                |            |         |        |        |             |  |  |                 |                  |            |                  |              |          |  |
|                    |                |        |    |                |            |         |        |        |             |  |  |                 |                  |            |                  |              |          |  |

Distances

Object Volumes

**Figure A.1:** The figure shows the entropy calculation performed for the game scene Aion\_1.

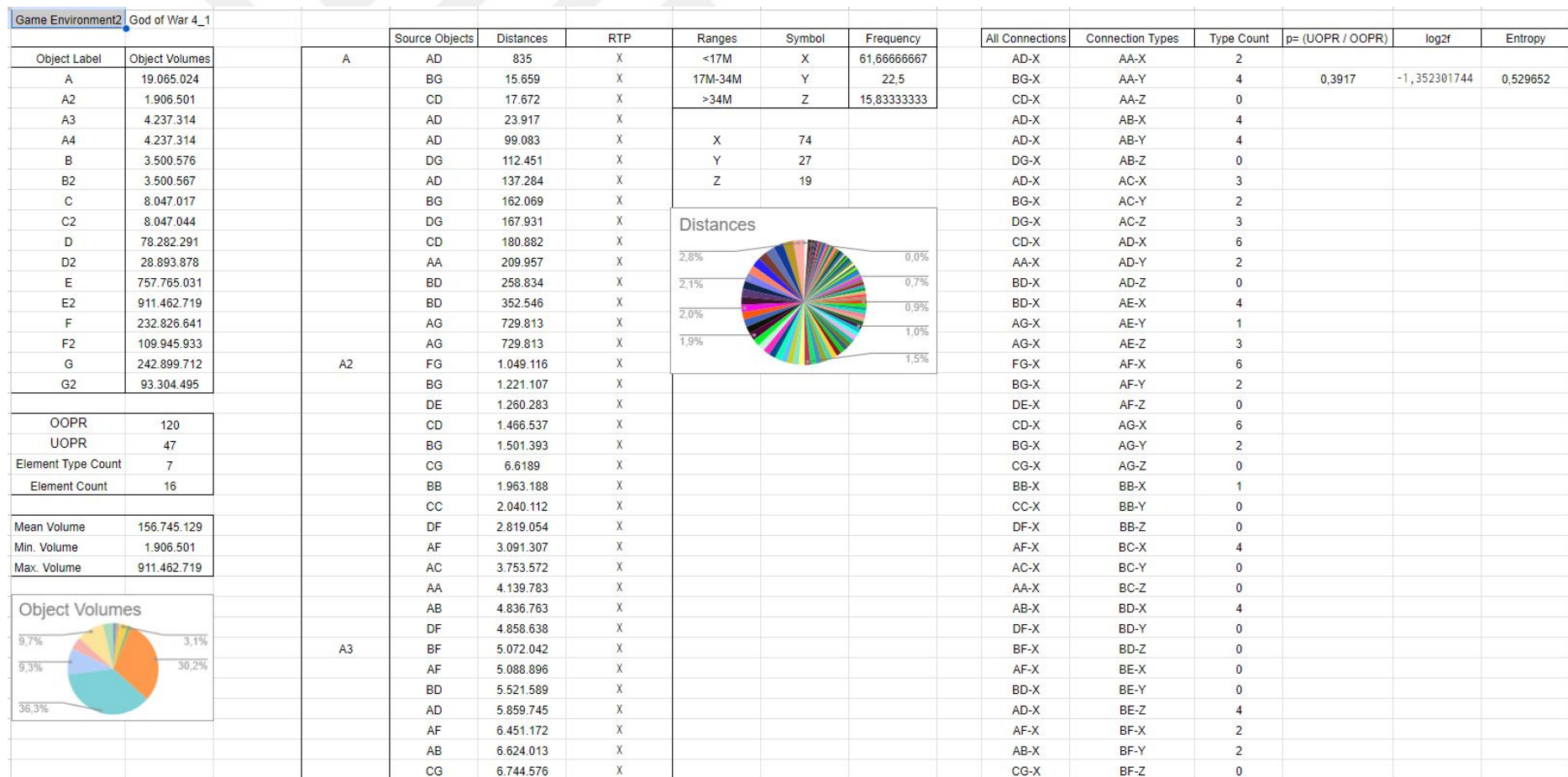


**Figure A.2:** The figure shows the entropy calculation performed for the game scene God of War 4\_1.

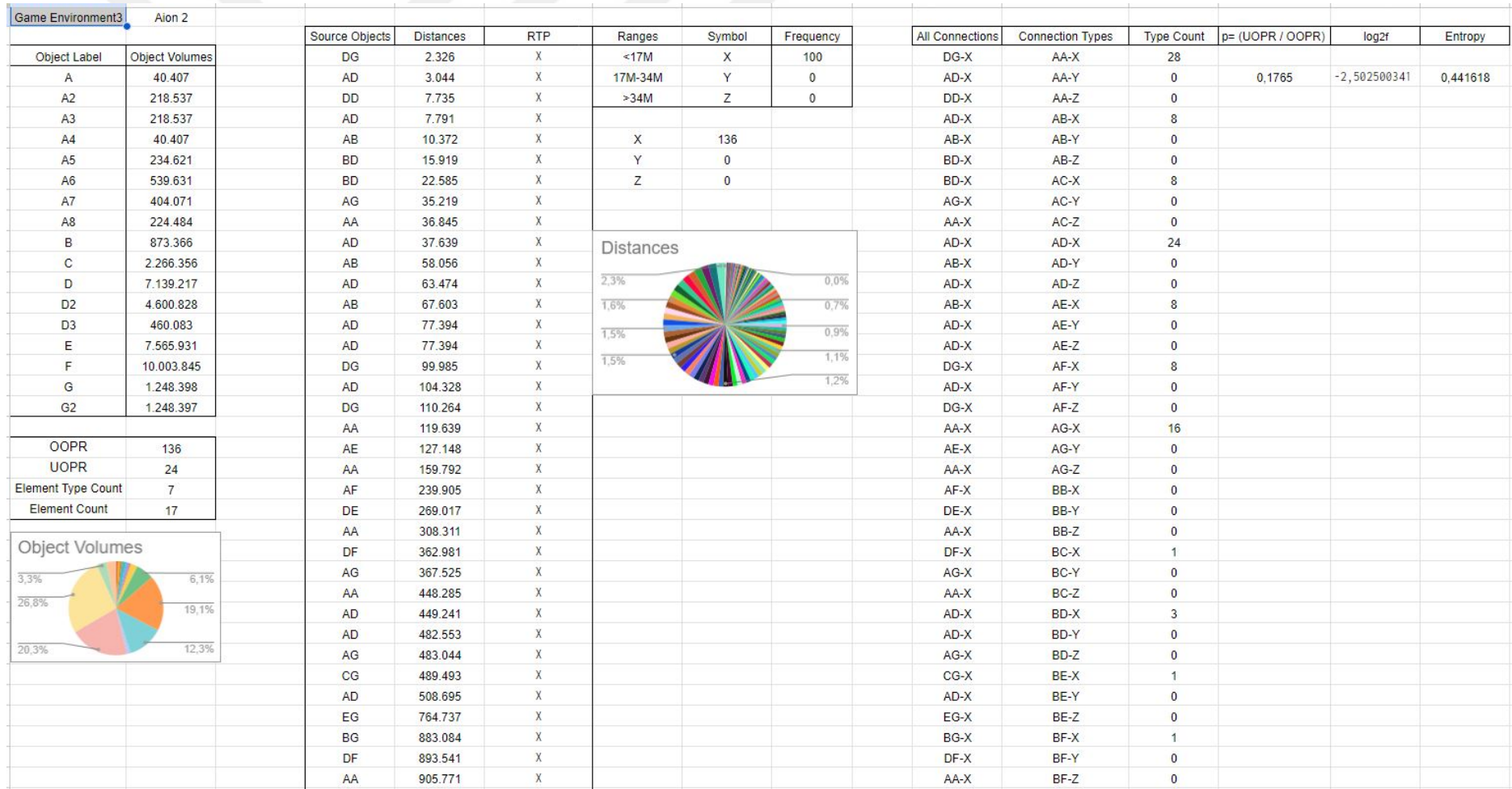


**Figure A.3:** The figure shows the entropy calculation performed for the game scene Aion\_2.

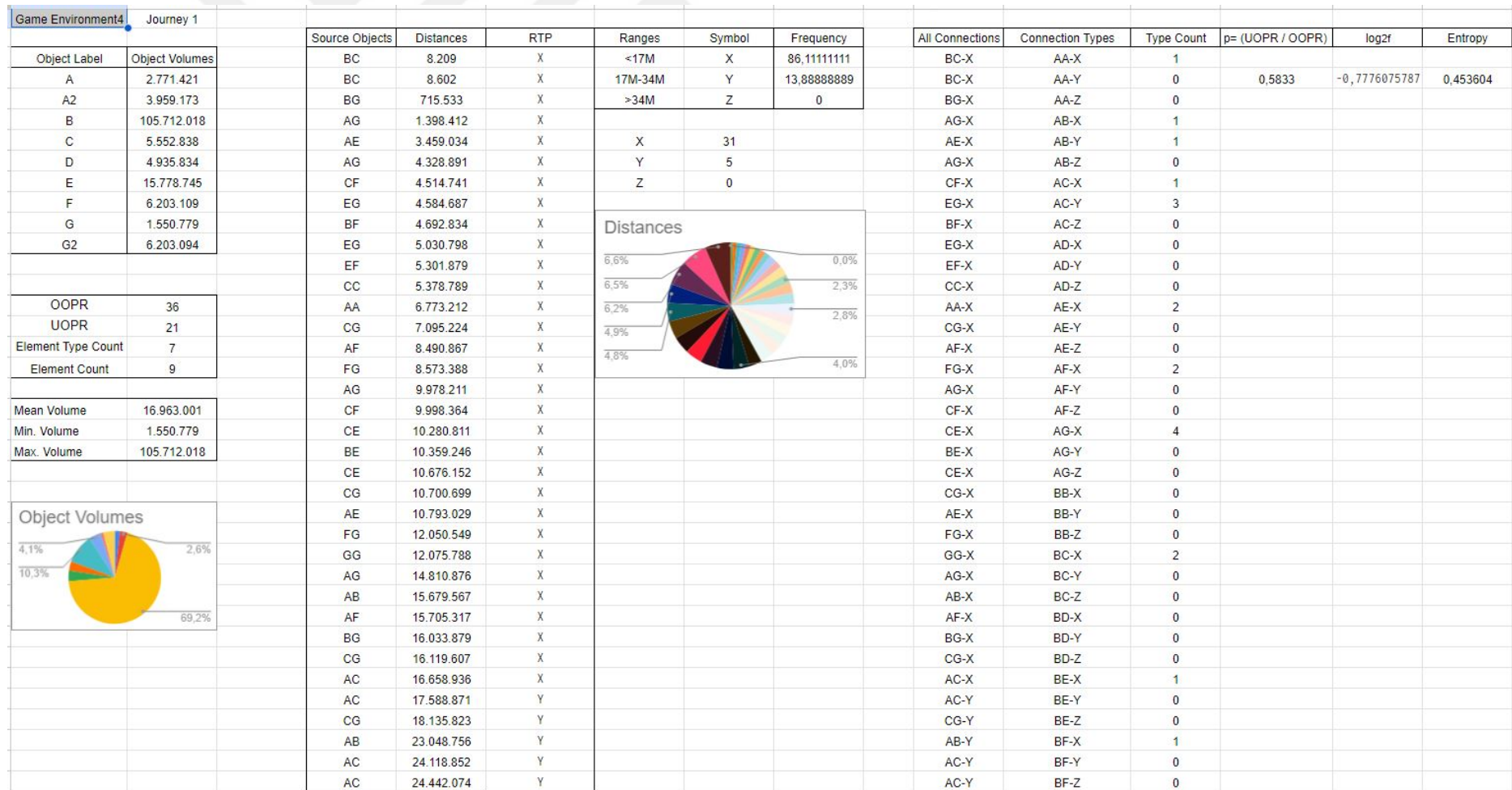


**Figure A.4:** The figure shows the entropy calculation performed for the game scene Journey\_1.

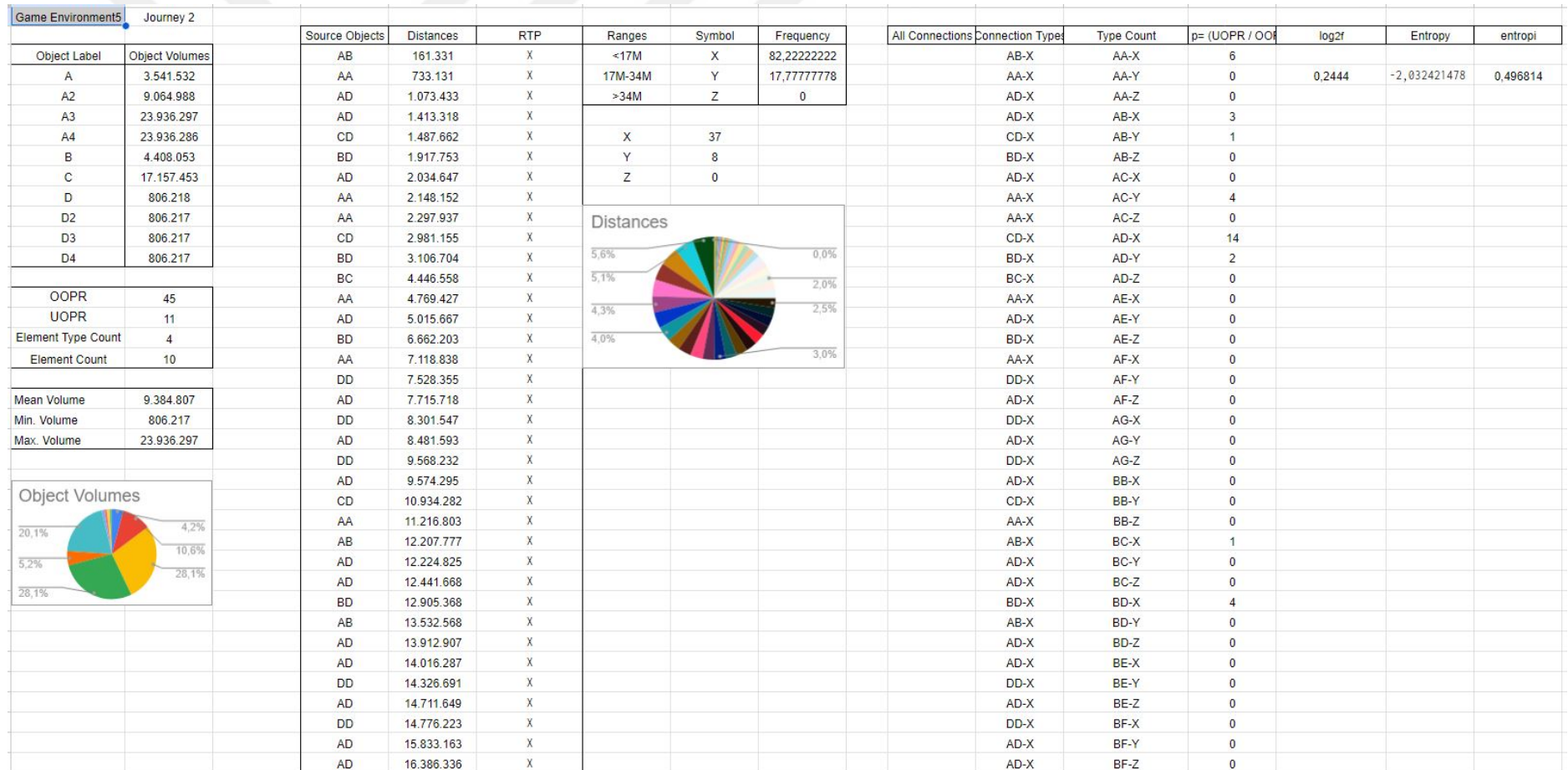


**Figure A.5:** The figure shows the entropy calculation performed for the game scene Journey\_2.

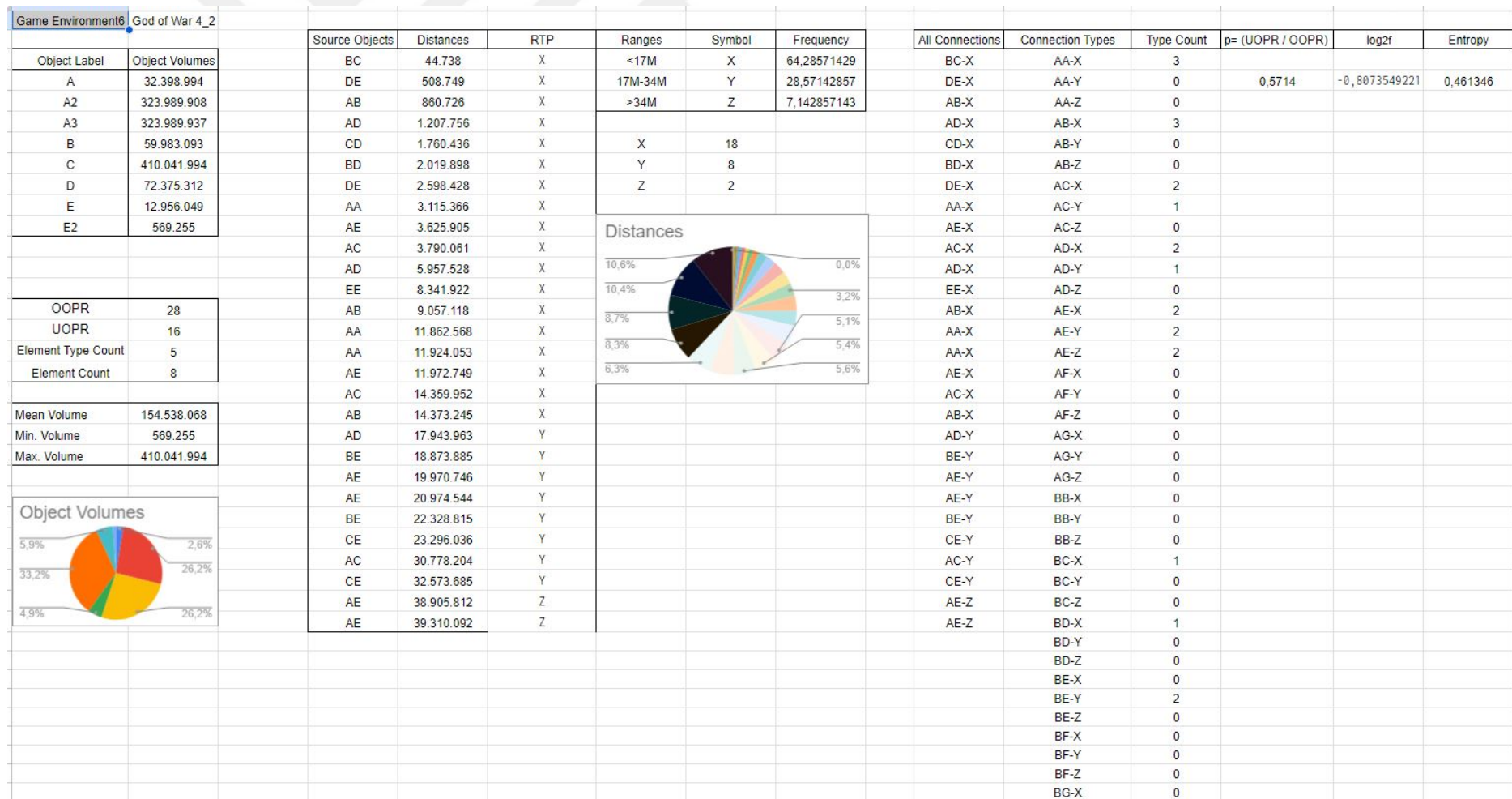


**Figure A.6:** The figure shows the entropy calculation performed for the game scene God of War 4\_2.

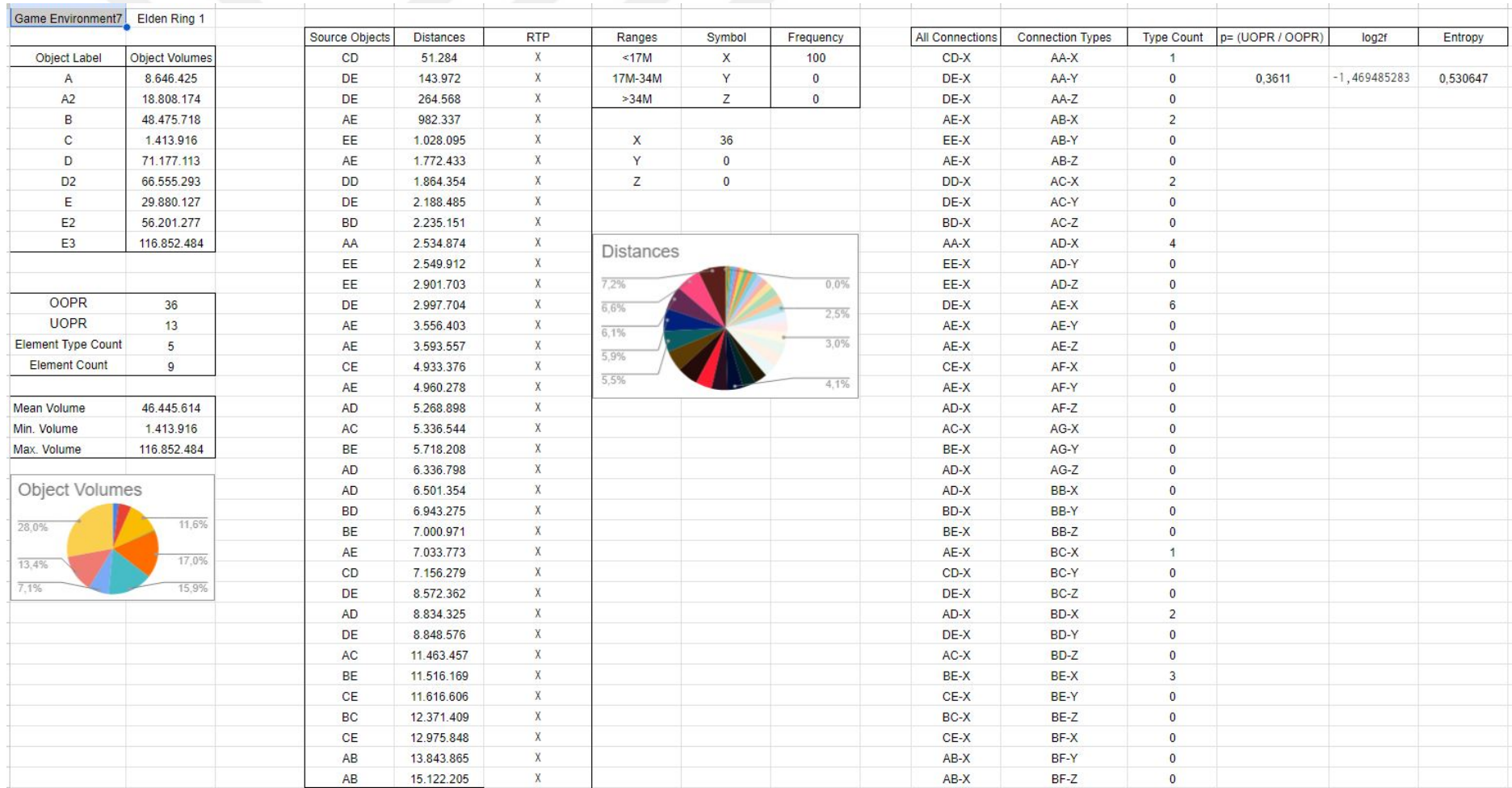


**Figure A.7:** The figure shows the entropy calculation performed for the game scene Elden Ring\_1.

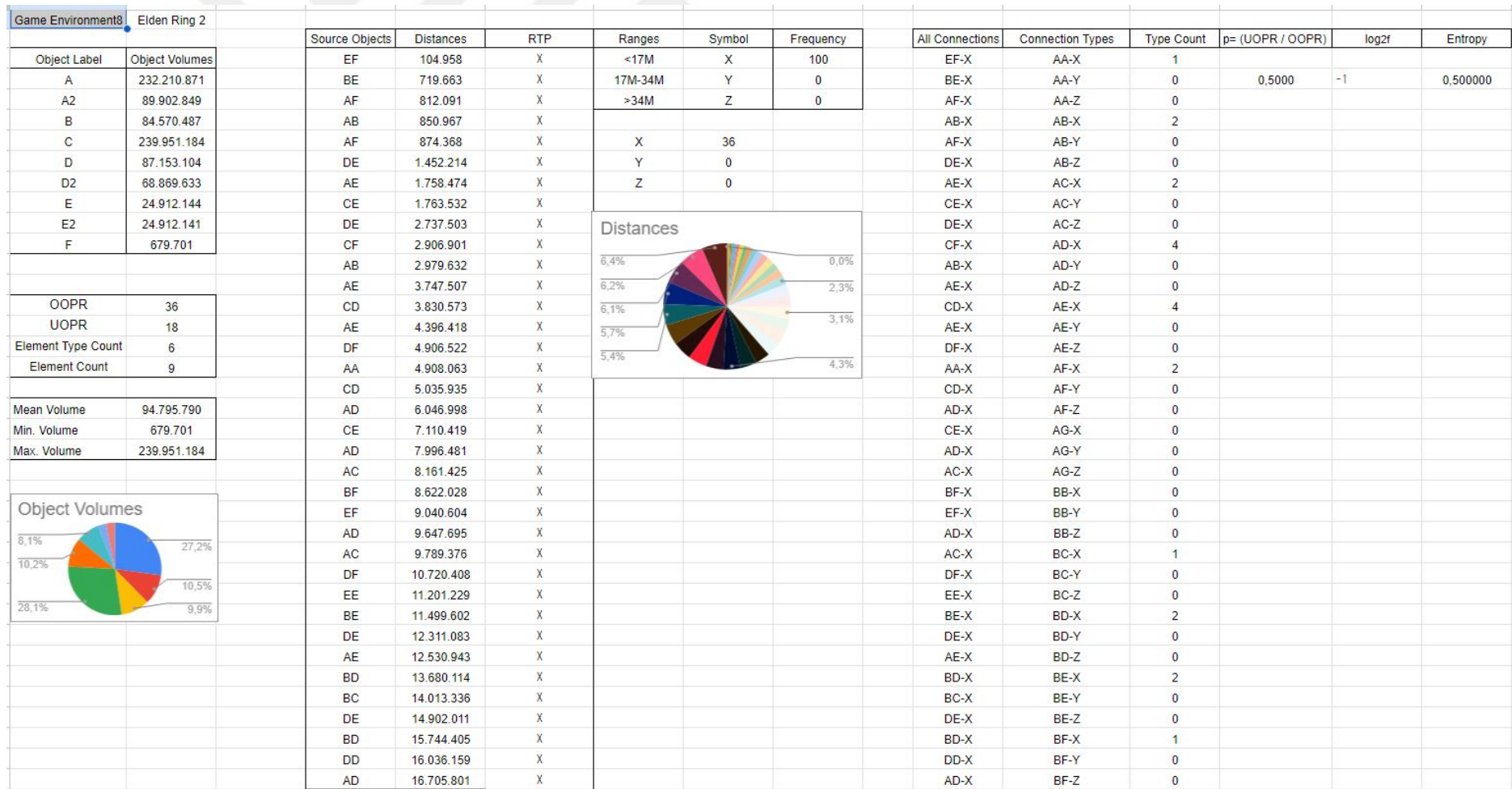


**Figure A.8:** The figure shows the entropy calculation performed for the game scene Elden Ring\_2.

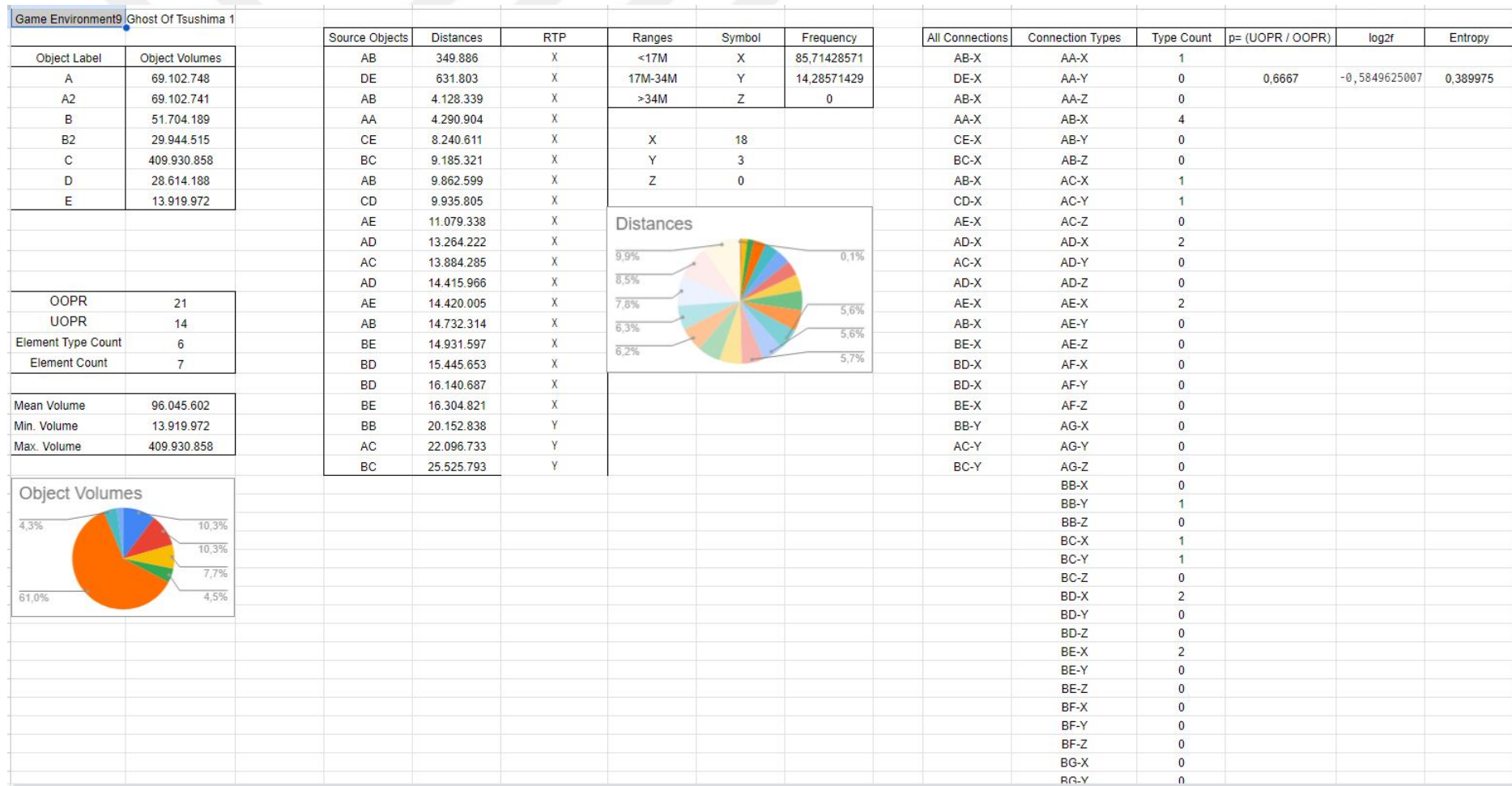


**Figure A.9:** The figure shows the entropy calculation performed for the game scene Ghost of Tsushima\_1.

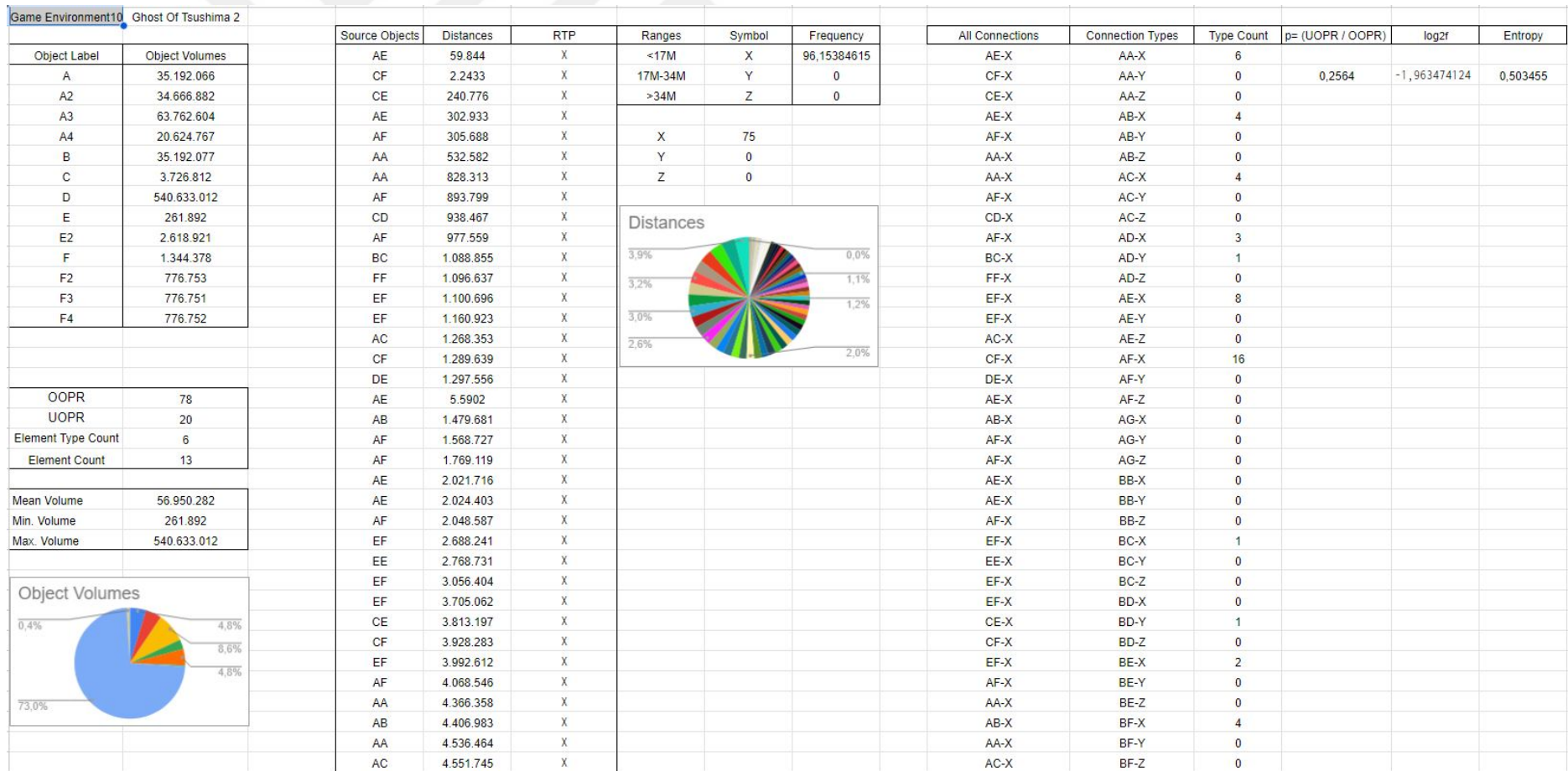


**Figure A.10:** The figure shows the entropy calculation performed for the game scene Ghost of Tsushima\_2.

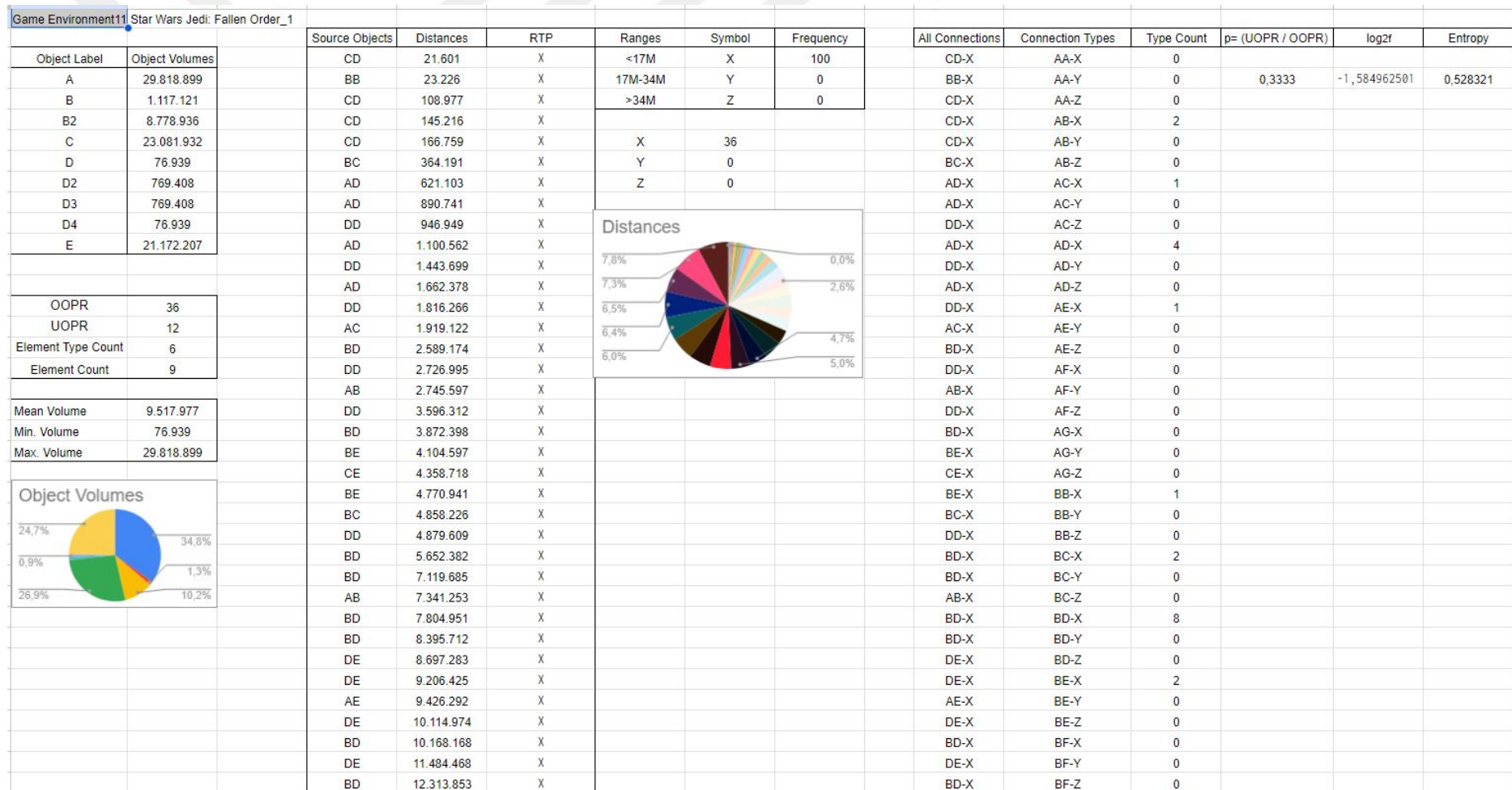


**Figure A.11:** The figure shows the entropy calculation performed for the game scene Star Wars Jedi: Fallen Order\_1.

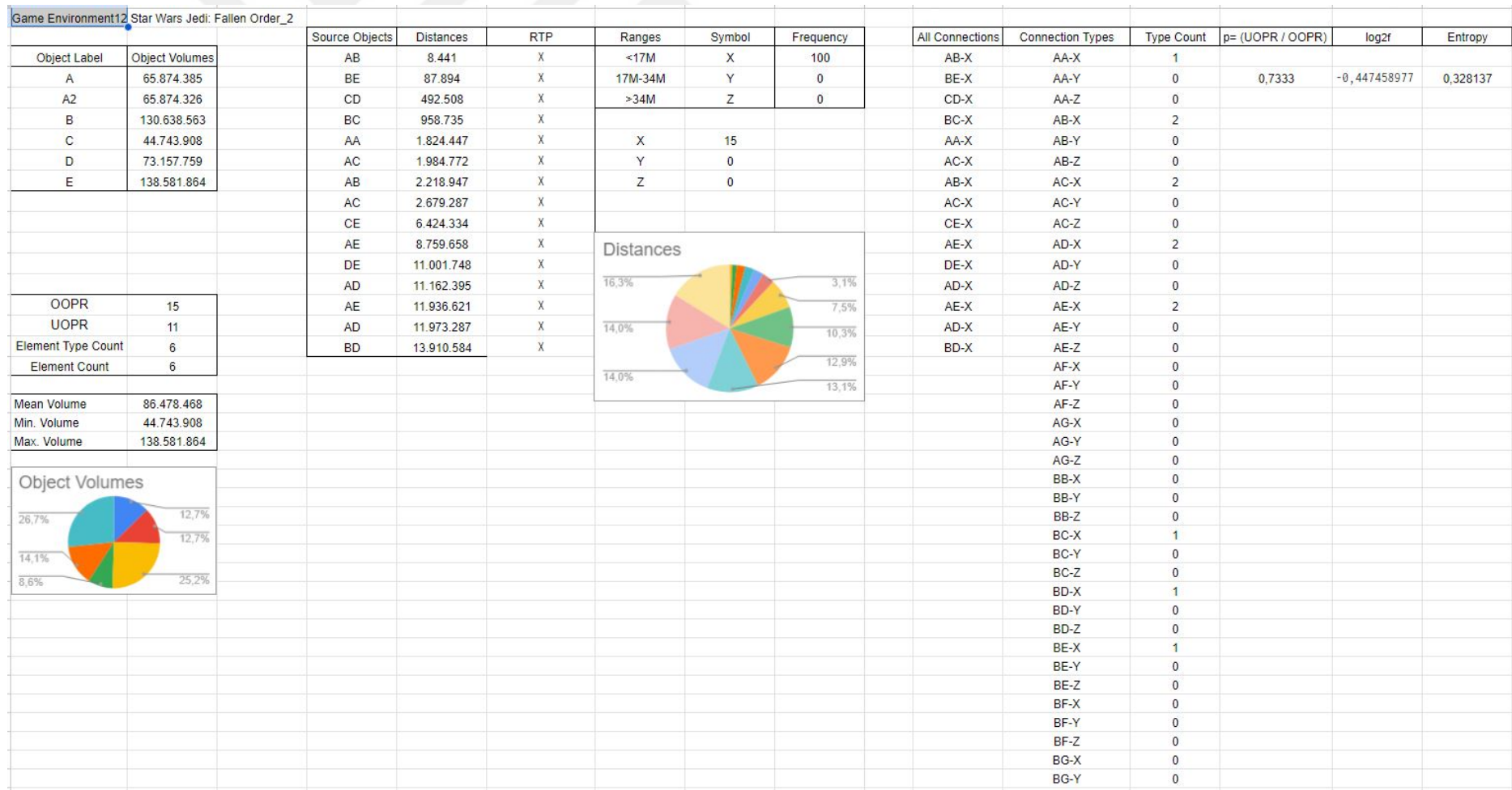


**Figure A.12:** The figure shows the entropy calculation performed for the game scene Star Wars Jedi: Fallen Order\_2.

| Game Environment13 |                | Control 1      |           |     |         |        |             |                 |                  |            |                  |              |          |  |  |
|--------------------|----------------|----------------|-----------|-----|---------|--------|-------------|-----------------|------------------|------------|------------------|--------------|----------|--|--|
| Object Label       | Object Volumes | Source Objects | Distances | RTP | Ranges  | Symbol | Frequency   | All Connections | Connection Types | Type Count | p= (UOPR / OOPR) | log2t        | Entropy  |  |  |
| A                  | 4.028.807.982  | 186.443        | BE        | X   | <17M    | X      | 40          | BE-X            | AA-X             | 0          |                  |              |          |  |  |
| B                  | 152.197.536    | 460.602        | AB        | X   | 17M-34M | Y      | 29,09090909 | AB-X            | AA-Y             | 0          | 0,4000           | -1,321928095 | 0,528771 |  |  |
| C1                 | 624.571.699    | 479.658        | BC        | X   | >34M    | Z      | 30,90909091 | BC-X            | AA-Z             | 0          |                  |              |          |  |  |
| C2                 | 624.571.699    | 1.262.982      | CE        | X   |         |        |             | CE-X            | AB-X             | 1          |                  |              |          |  |  |
| C3                 | 62.457.188     | 1.518.877      | CD        | X   |         |        |             | CD-X            | AB-Y             | 0          |                  |              |          |  |  |
| C4                 | 62.457.188     | 1.653.555      | CD        | X   | X       | 22     |             | CD-X            | AB-Z             | 0          |                  |              |          |  |  |
| D1                 | 163.007.562    | 1.896.511      | CD        | X   | Y       | 16     |             | CD-X            | AC-X             | 2          |                  |              |          |  |  |
| D2                 | 1.630.074.249  | 2.045.115      | CD        | X   | Z       | 17     |             | CD-X            | AC-Y             | 0          |                  |              |          |  |  |
| D3                 | 1.630.074.249  | 2.483.586      | DE        | X   |         |        |             | DE-X            | AC-Z             | 2          |                  |              |          |  |  |
| D4                 | 1.630.075.923  | 3.330.165      | CE        | X   |         |        |             | CE-X            | AD-X             | 2          |                  |              |          |  |  |
| E                  | 90.441.668     | 3.761.966      | DE        | X   |         |        |             | DE-X            | AD-Y             | 0          |                  |              |          |  |  |
| OOPR               | 55             | 6.160.294      | BC        | X   |         |        |             | BC-X            | AD-Z             | 2          |                  |              |          |  |  |
| UOPR               | 22             | 7.401.794      | AE        | X   |         |        |             | AE-X            | AE-X             | 1          |                  |              |          |  |  |
| Element Type Count | 5              | 9.829.733      | BD        | X   |         |        |             | BD-X            | AE-Y             | 0          |                  |              |          |  |  |
| Element Count      | 11             | 11.180.686     | BD        | X   |         |        |             | BD-X            | AE-Z             | 0          |                  |              |          |  |  |
|                    |                | 11.630.327     | AD        | X   |         |        |             | AD-X            | AF-X             | 0          |                  |              |          |  |  |
|                    |                | 12.510.424     | AD        | X   |         |        |             | AD-X            | AF-Y             | 0          |                  |              |          |  |  |
| Mean Volume        | 1.060.829.528  | 12.746.018     | AC        | X   |         |        |             | AC-X            | AF-Z             | 0          |                  |              |          |  |  |
| Min. Volume        | 62.457.188     | 13.412.797     | AC        | X   |         |        |             | AC-X            | AG-X             | 0          |                  |              |          |  |  |
| Max. Volume        | 4.028.807.982  | 15.571.897     | CD        | X   |         |        |             | CD-X            | AG-Y             | 0          |                  |              |          |  |  |
|                    |                | 16.539.735     | CD        | X   |         |        |             | CD-X            | AG-Z             | 0          |                  |              |          |  |  |
|                    |                | 16.903.921     | CE        | X   |         |        |             | CE-X            | BB-X             | 0          |                  |              |          |  |  |
|                    |                | 20.879.978     | CC        | Y   |         |        |             | CC-Y            | BB-Y             | 0          |                  |              |          |  |  |
|                    |                | 20.880.116     | CC        | Y   |         |        |             | CC-Y            | BB-Z             | 0          |                  |              |          |  |  |
|                    |                | 24.540.775     | DE        | Y   |         |        |             | DE-Y            | BC-X             | 2          |                  |              |          |  |  |
|                    |                | 25.738.729     | DD        | Y   |         |        |             | DD-Y            | BC-Y             | 0          |                  |              |          |  |  |
|                    |                | 25.738.729     | DD        | Y   |         |        |             | DD-Y            | BC-Z             | 2          |                  |              |          |  |  |
|                    |                | 27.739.077     | CC        | Y   |         |        |             | CC-Y            | BD-X             | 2          |                  |              |          |  |  |
|                    |                | 27.739.077     | CC        | Y   |         |        |             | CC-Y            | BD-Y             | 2          |                  |              |          |  |  |
|                    |                | 28.003.485     | BD        | Y   |         |        |             | BD-Y            | BD-Z             | 0          |                  |              |          |  |  |
|                    |                | 28.266.479     | CD        | Y   |         |        |             | CD-Y            | BE-X             | 1          |                  |              |          |  |  |
|                    |                | 28.362.066     | CD        | Y   |         |        |             | CD-Y            | BE-Y             | 0          |                  |              |          |  |  |
|                    |                | 28.943.504     | CD        | Y   |         |        |             | CD-Y            | BE-Z             | 0          |                  |              |          |  |  |
|                    |                | 28.997.844     | CD        | Y   |         |        |             | CD-Y            | BF-X             | 0          |                  |              |          |  |  |
|                    |                | 30.415.013     | BD        | Y   |         |        |             | BD-Y            | BF-Y             | 0          |                  |              |          |  |  |
|                    |                | 32.505.198     | CD        | Y   |         |        |             | CD-Y            | BF-Z             | 0          |                  |              |          |  |  |

Distances

Object Volumes

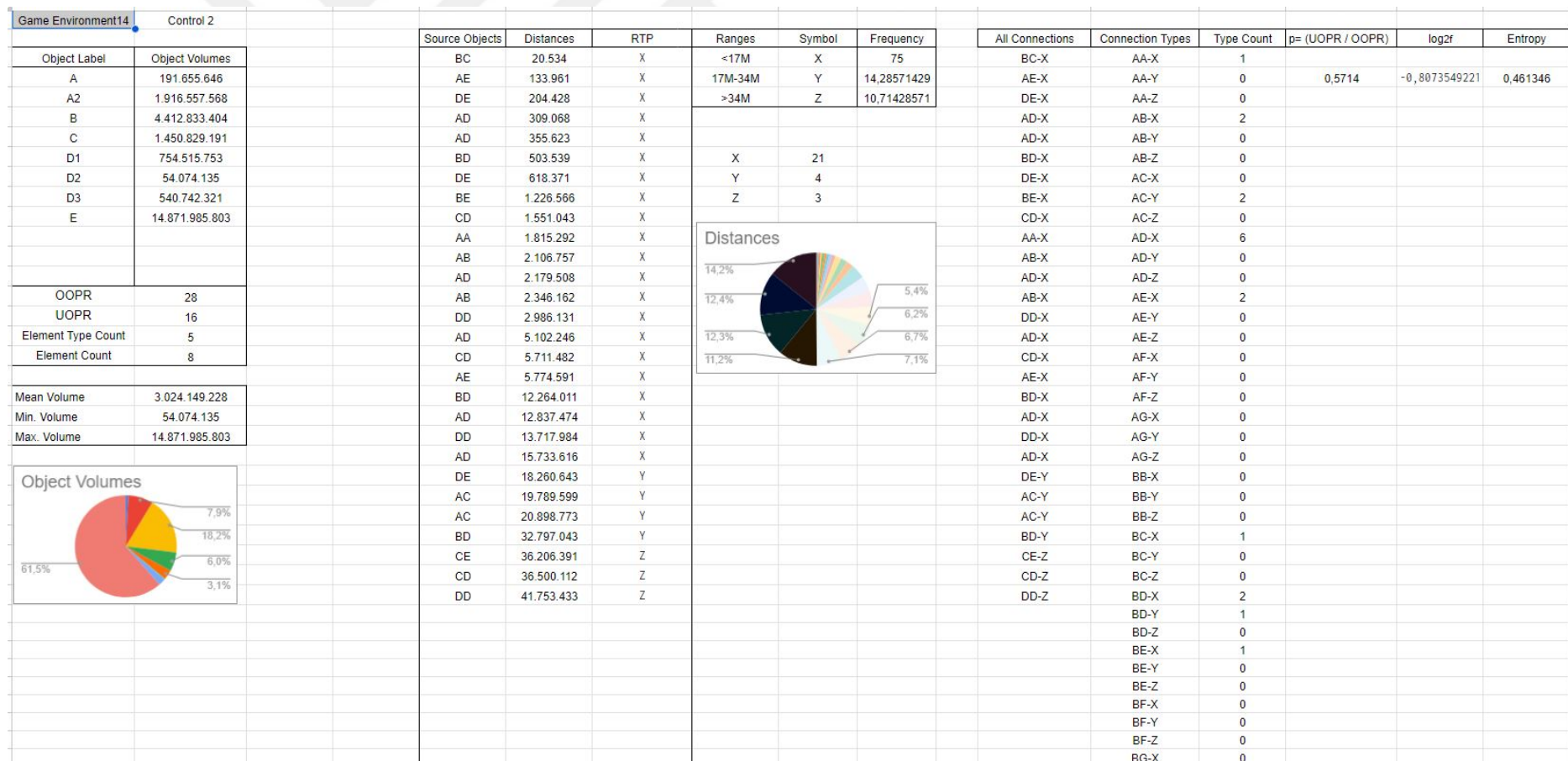


**Figure A.14:** The figure shows the entropy calculation performed for the game scene Control\_2.

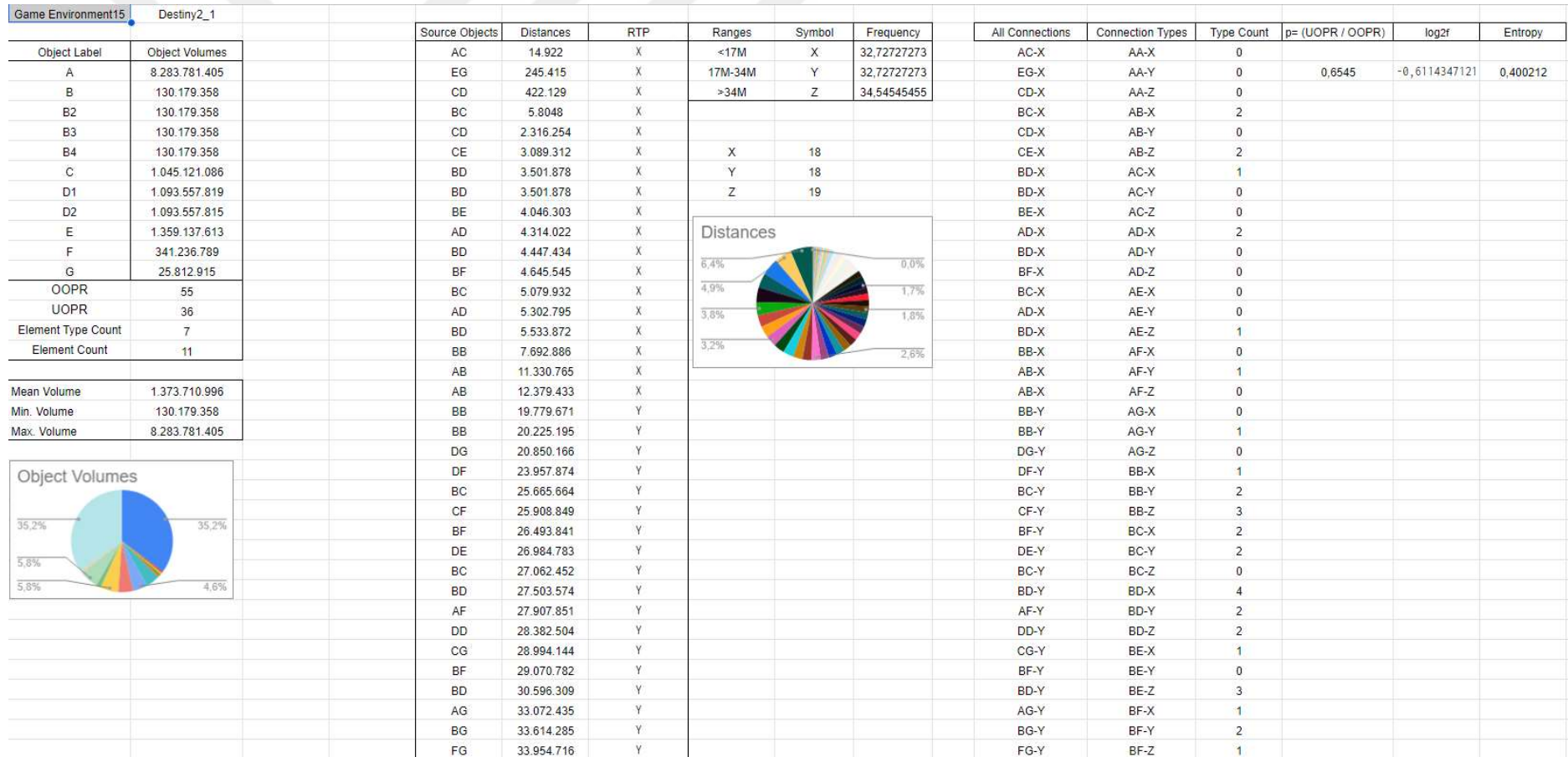


**Figure A.15:** The figure shows the entropy calculation performed for the game scene Destiny 2\_1.

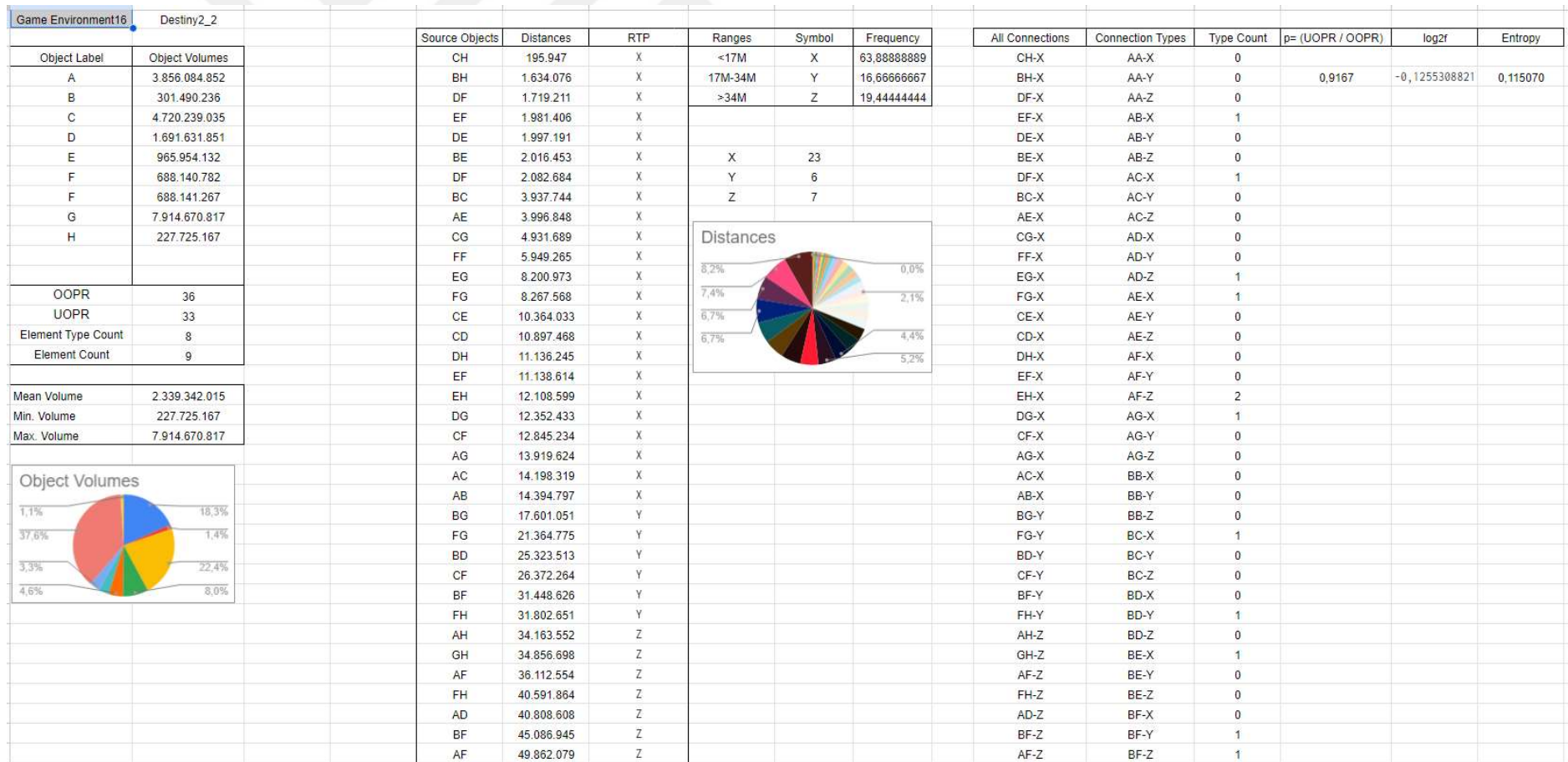


**Figure A.16:** The figure shows the entropy calculation performed for the game scene Destiny 2\_2.

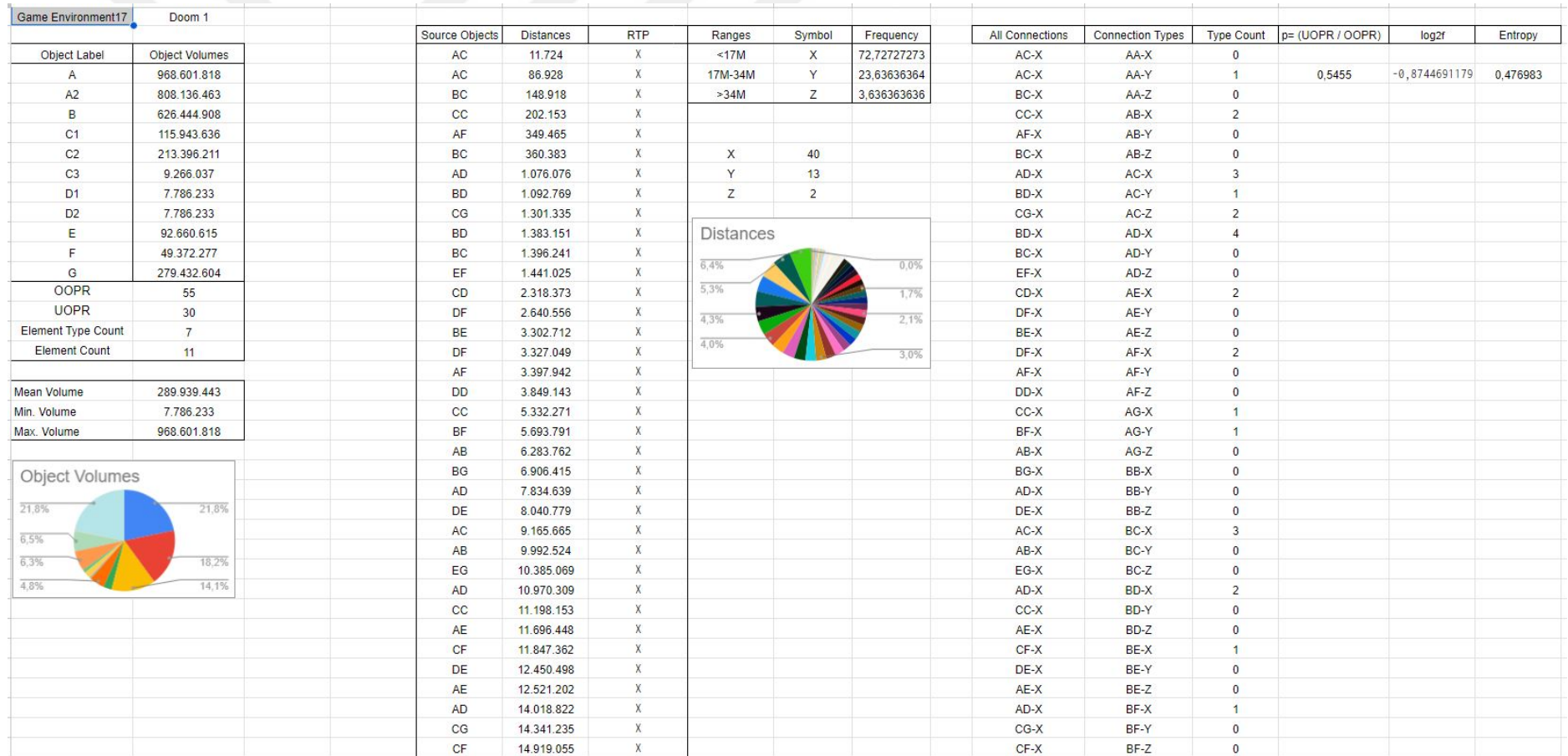


**Figure A.17:** The figure shows the entropy calculation performed for the game scene Doom\_1.

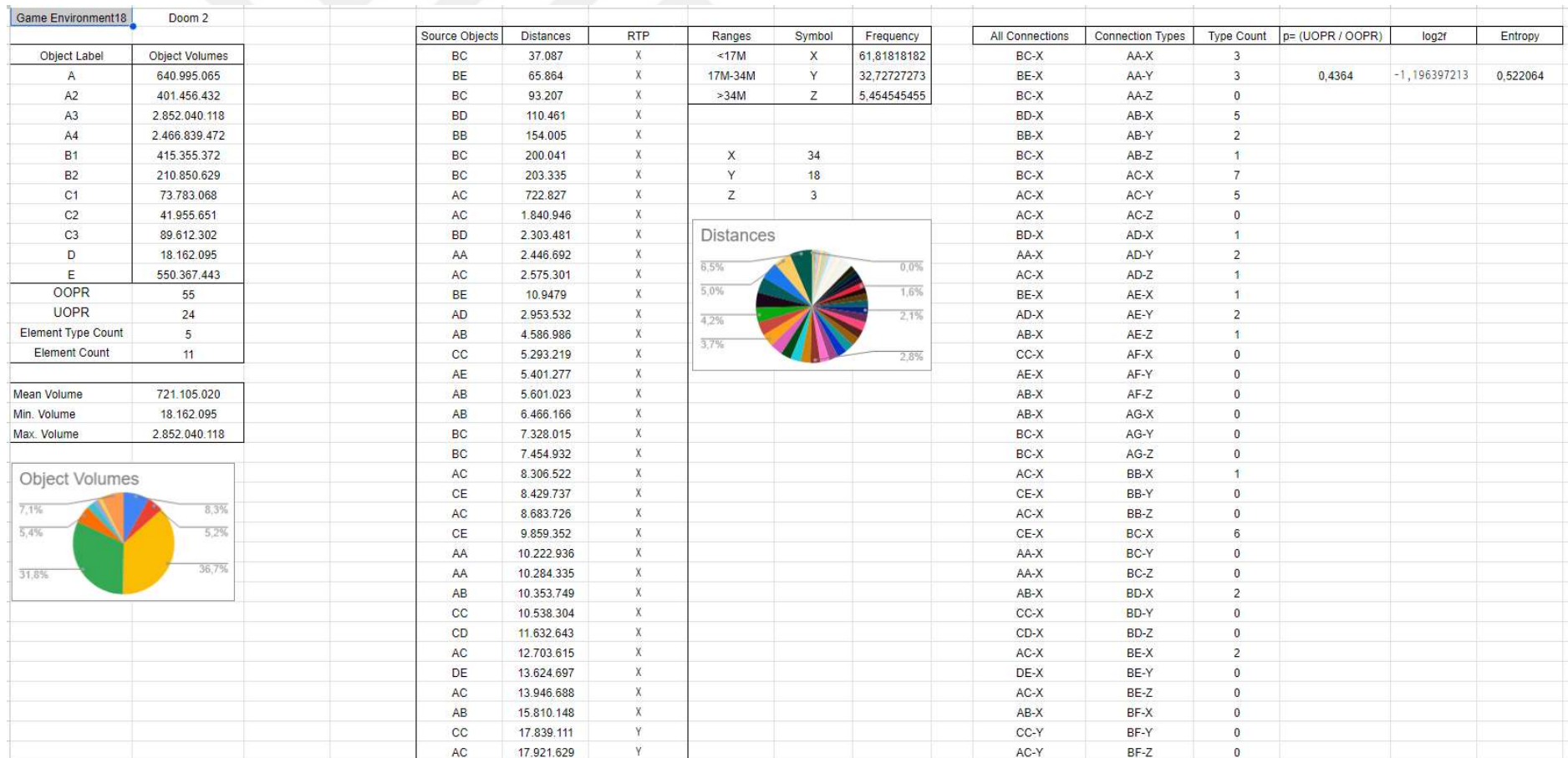


**Figure A.18:** The figure shows the entropy calculation performed for the game scene Doom\_2.

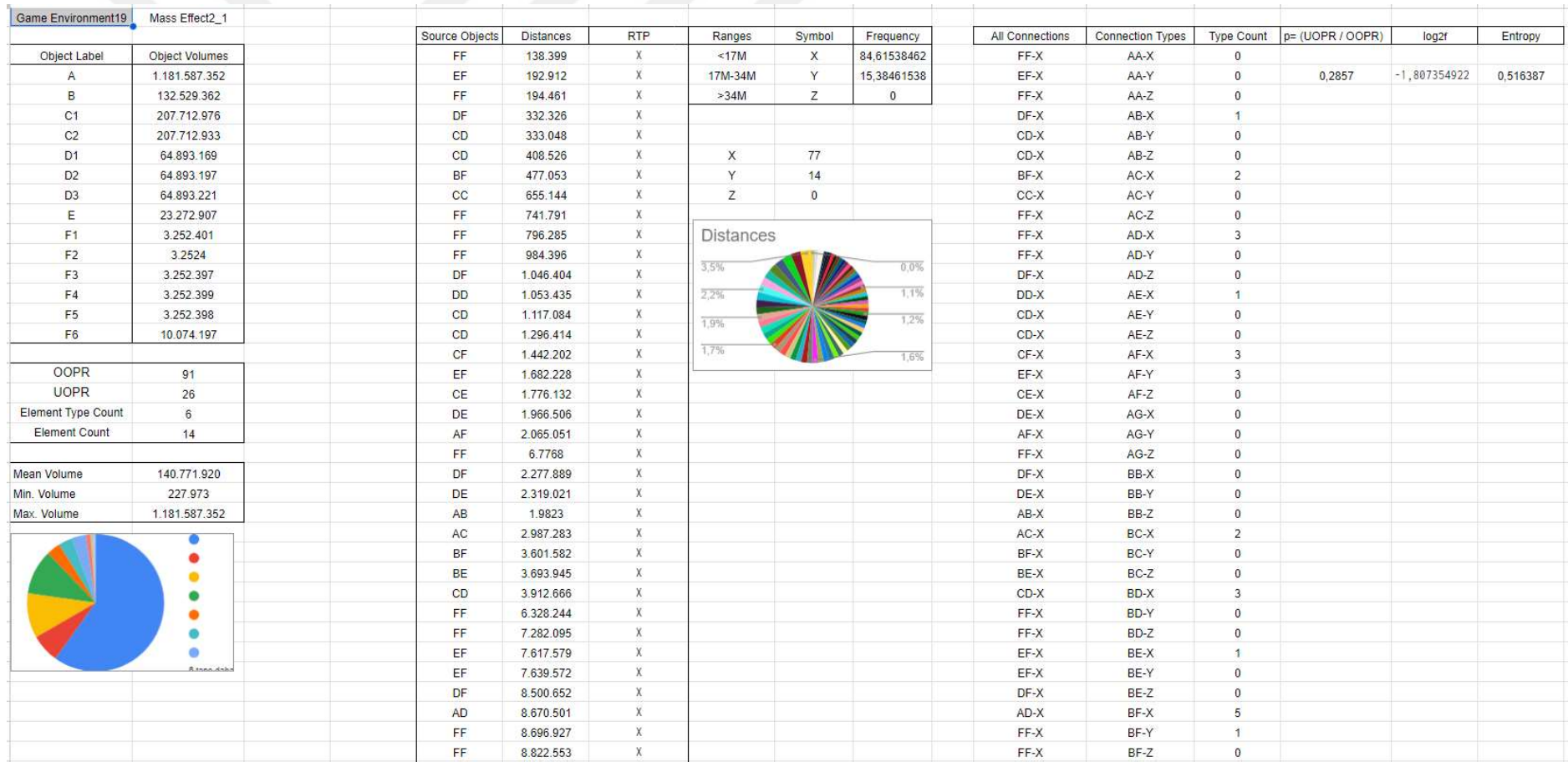


**Figure A.19:** The figure shows the entropy calculation performed for the game scene Mass Effect2\_1.

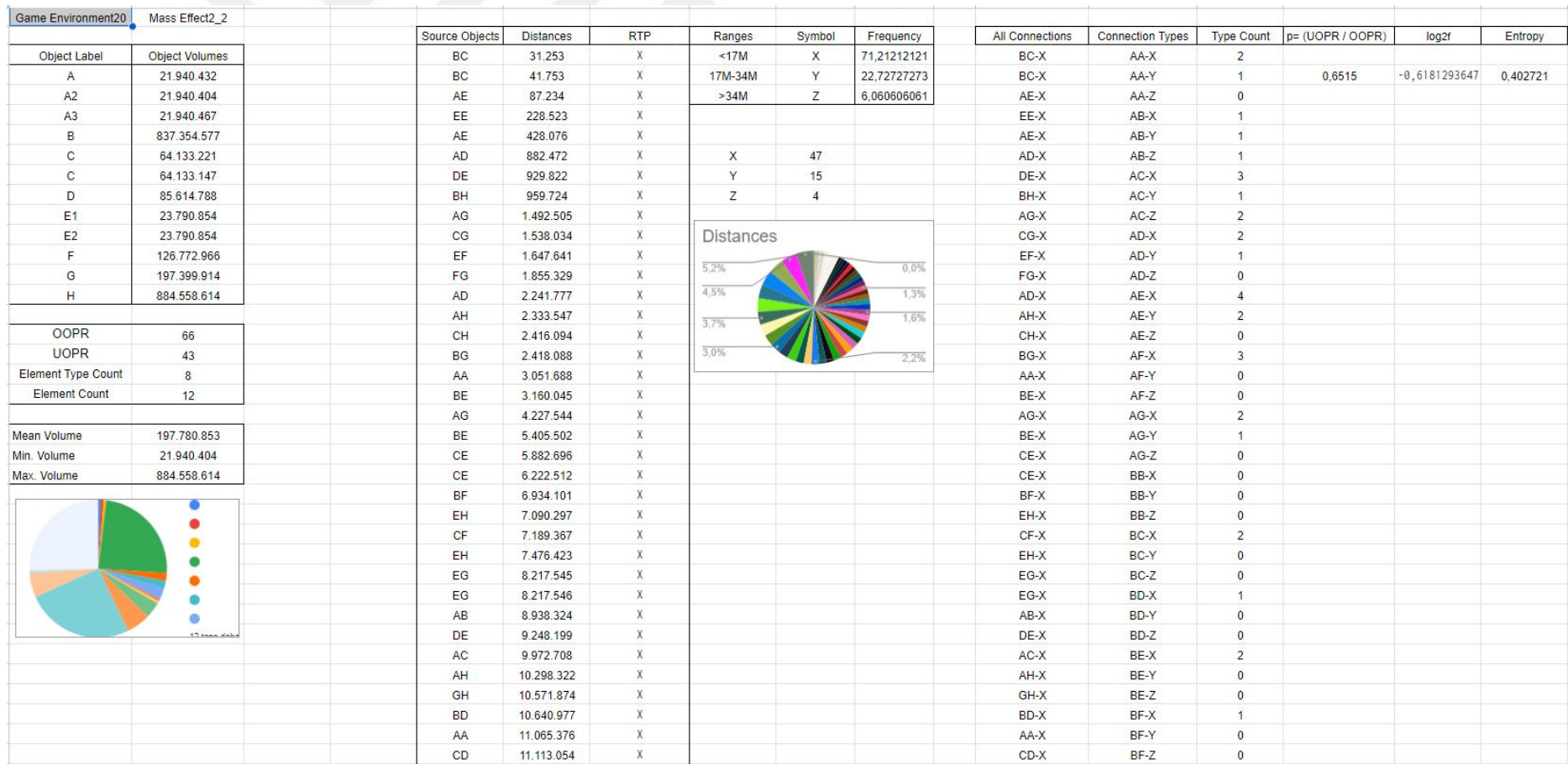


**Figure A.20:** The figure shows the entropy calculation performed for the game scene Mass Effect2\_2.

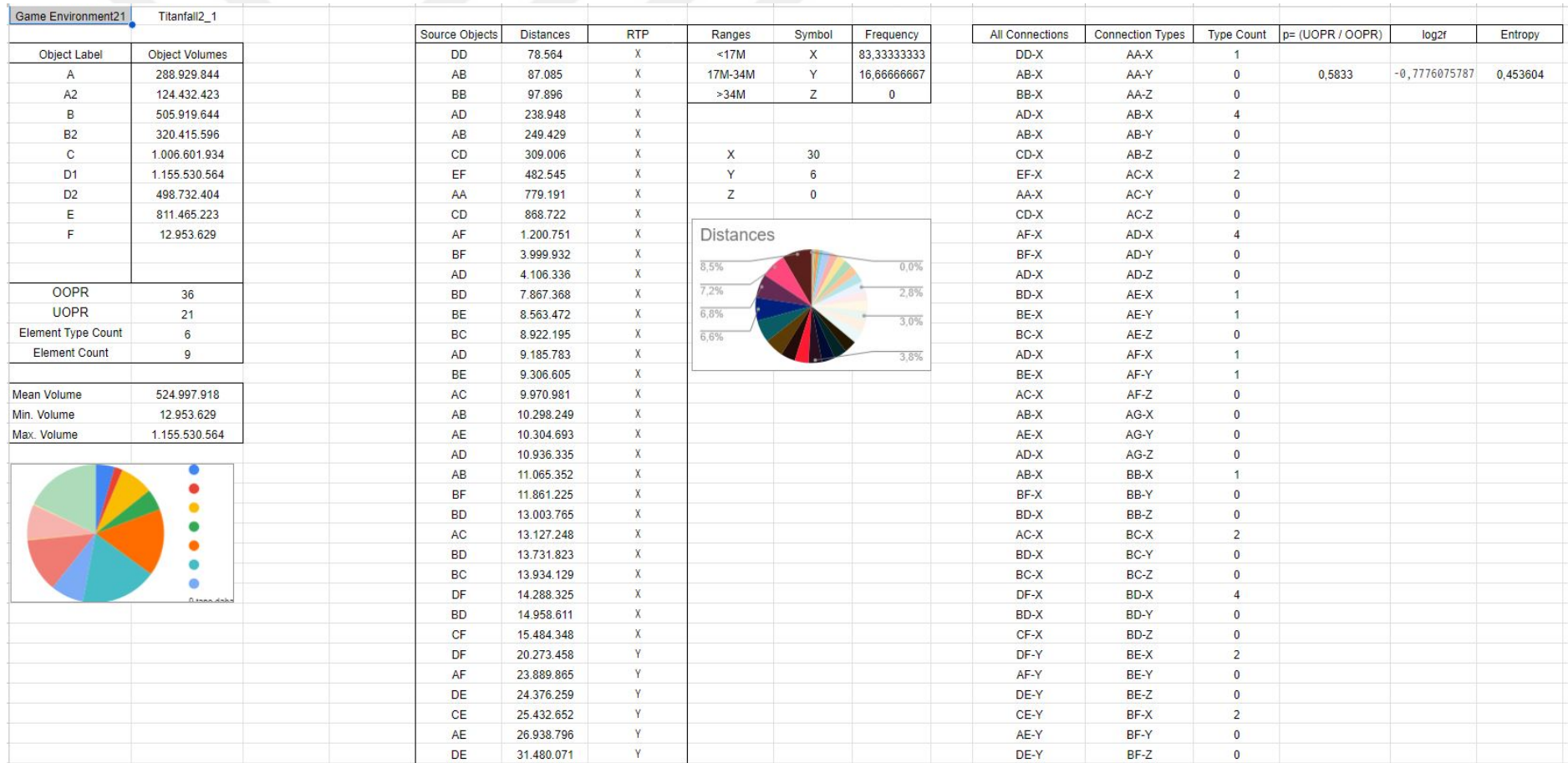


**Figure A.21:** The figure shows the entropy calculation performed for the game scene Titanfall2\_1.

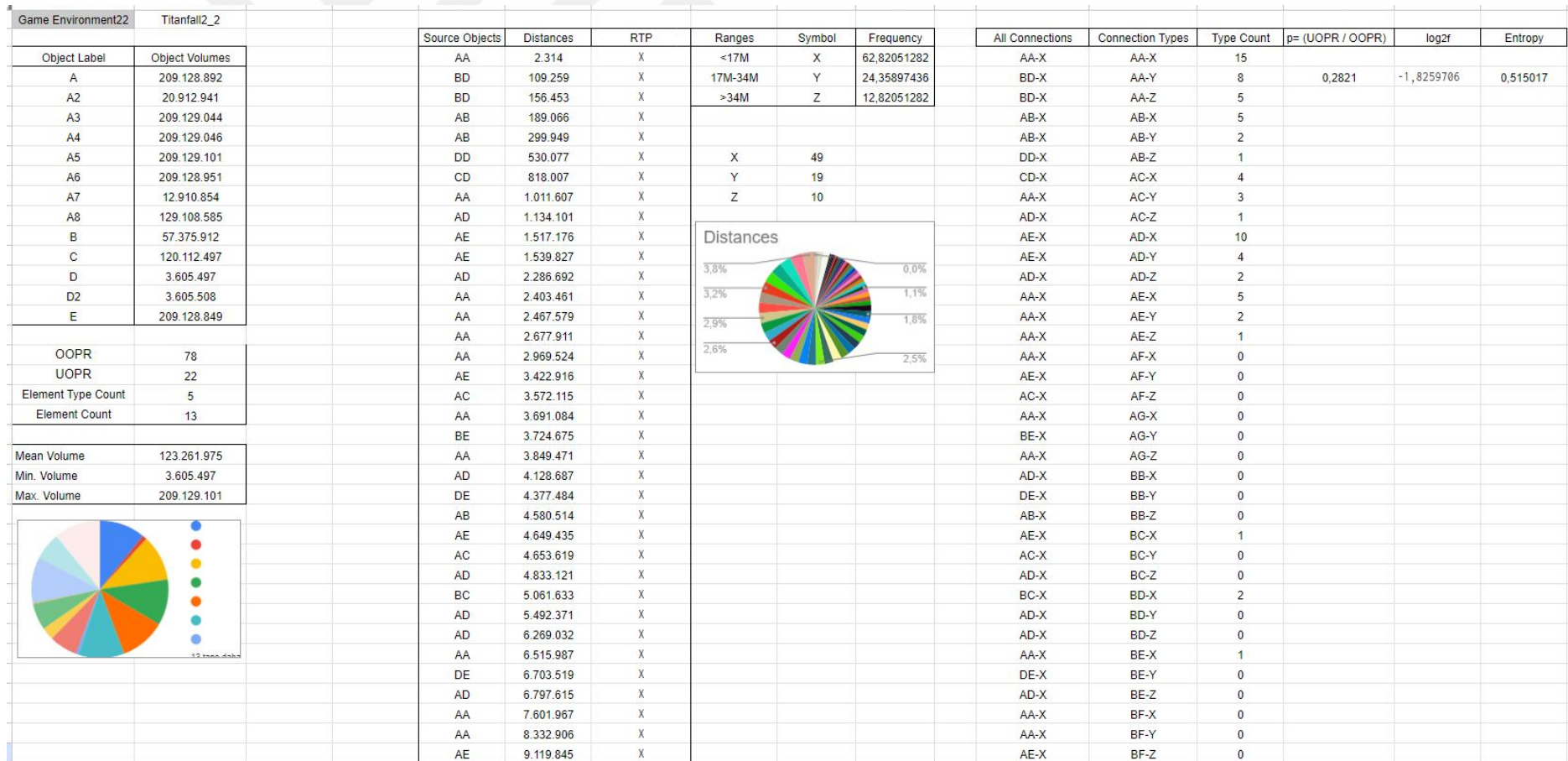


**Figure A.22:** The figure shows the entropy calculation performed for the game scene Titanfall2\_1.

## APPENDIX B: Representing & remodeling process of the games.

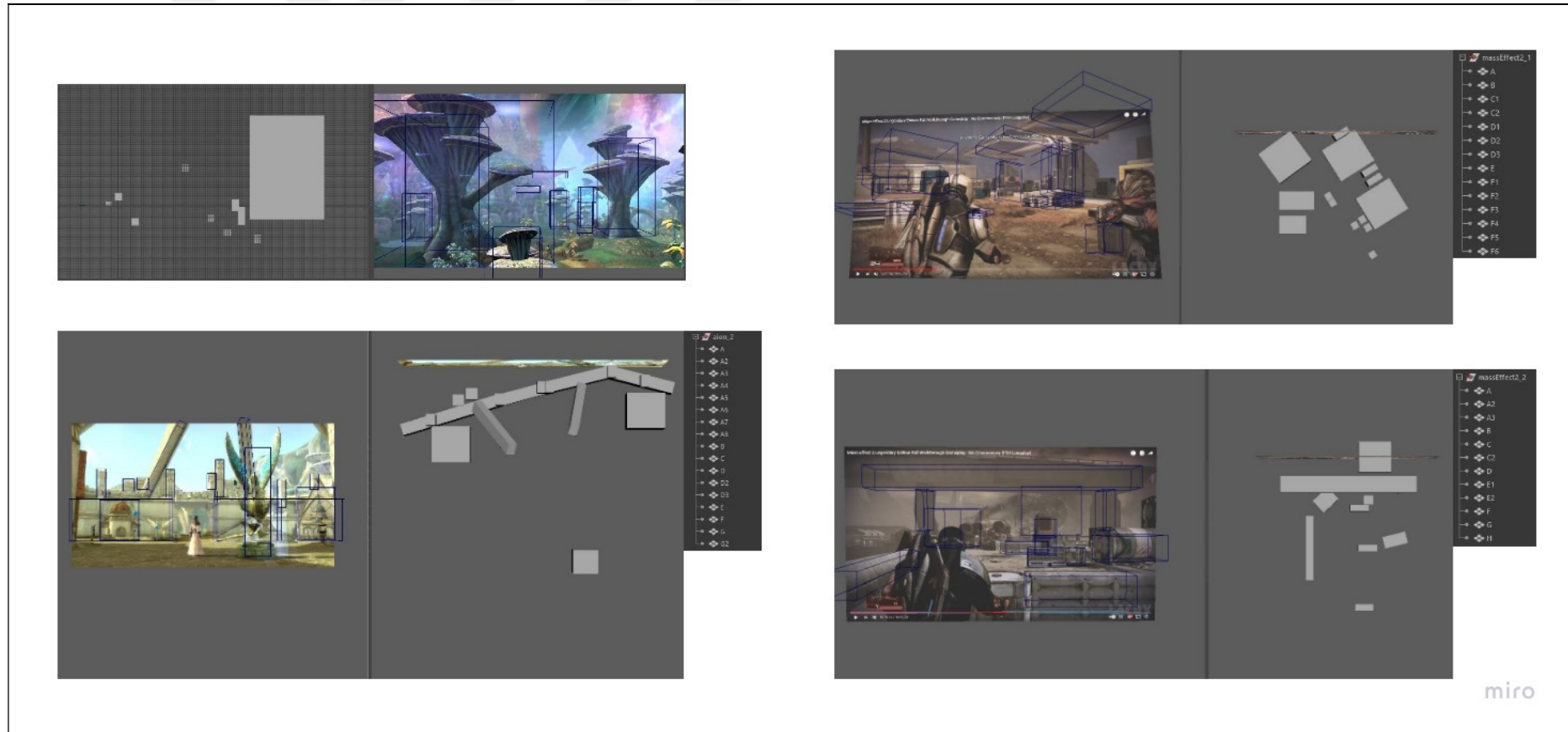


**Figure B.1:** The figure shows the representing & remodeling process of the game scenes Aion 1, 2 and Mass Effect 1, 2.

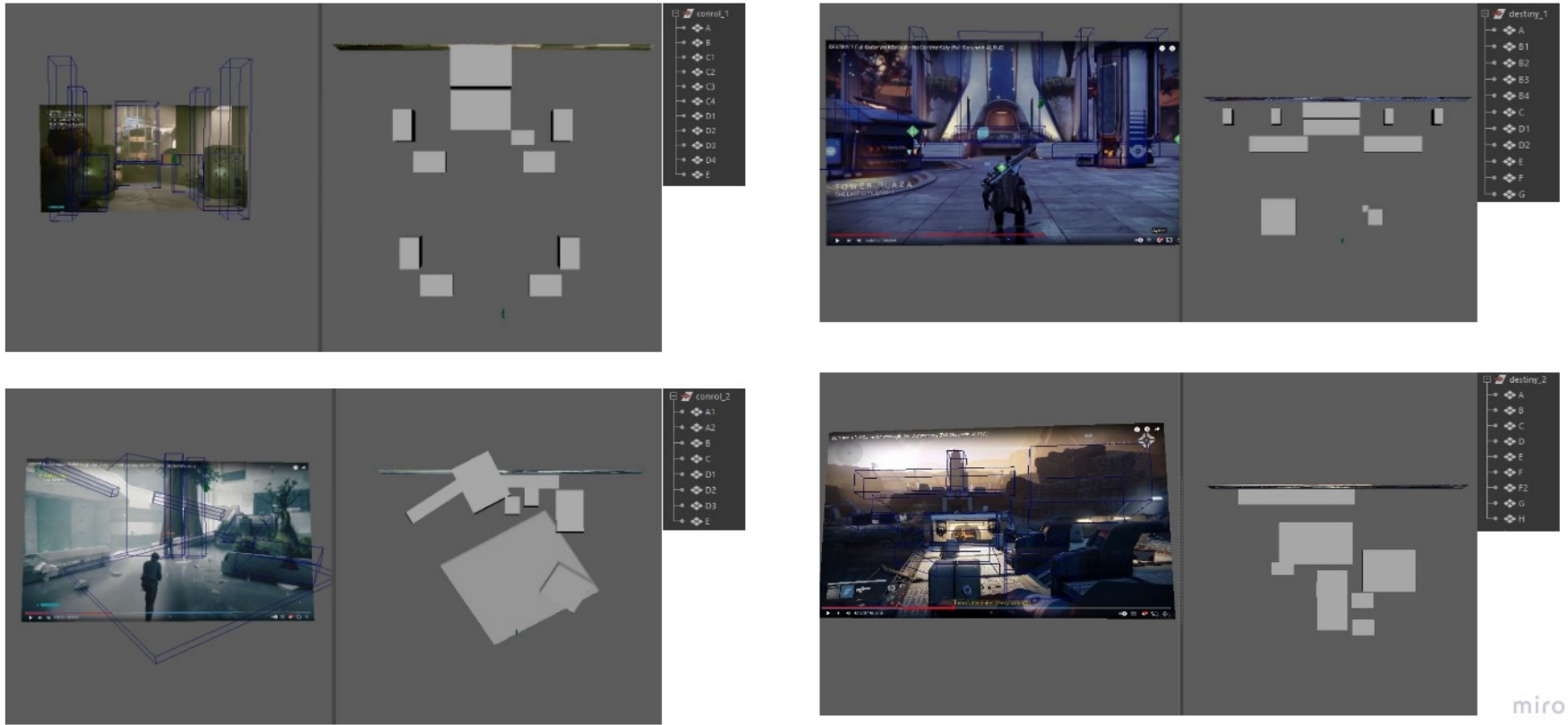


**Figure B.2:** The figure shows the representing & remodeling process of the game scenes Control 1, 2 and Destiny 1, 2.

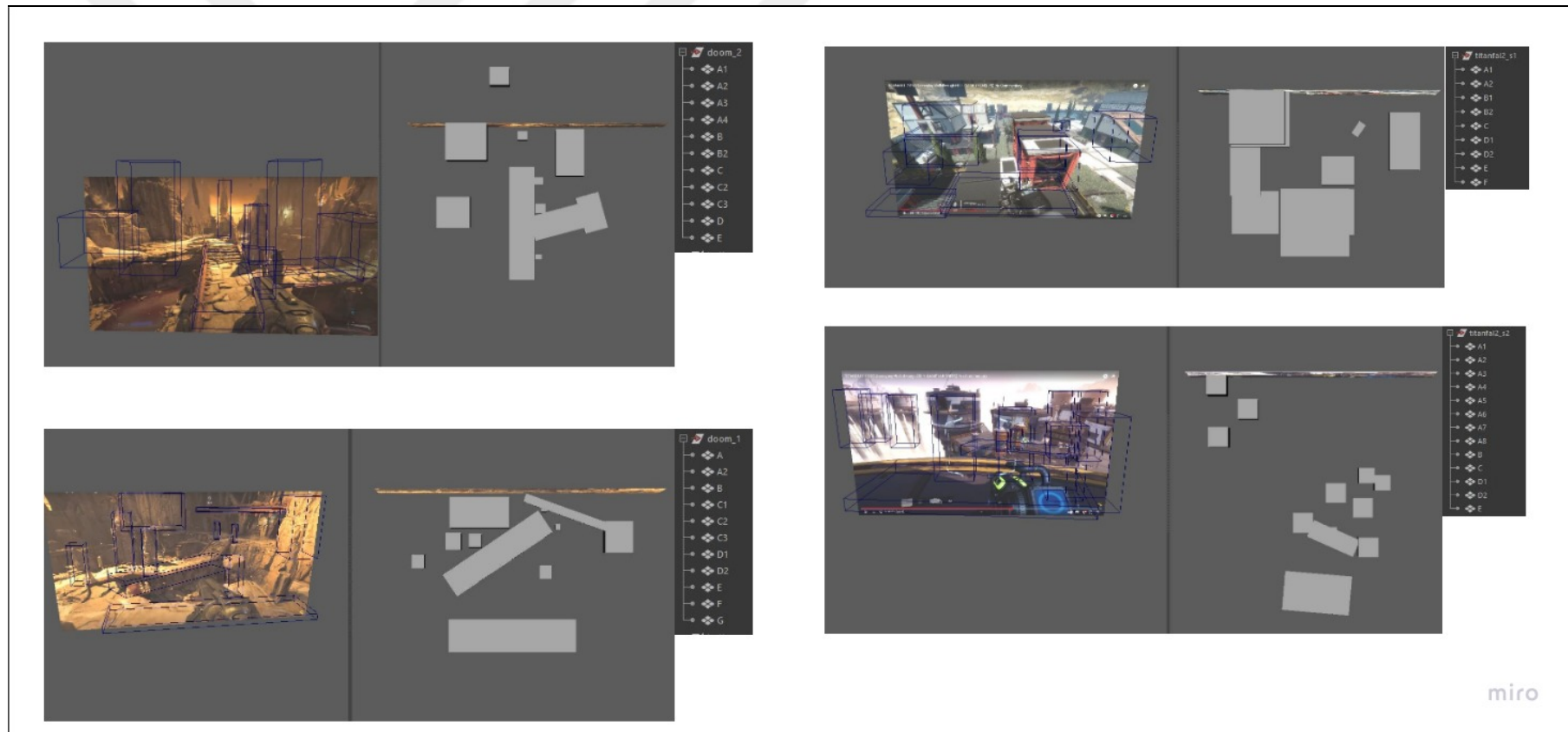


**Figure B.3:** The figure shows the representing & remodeling process of the game scenes Doom 1, 2 and Titanfall 1, 2.

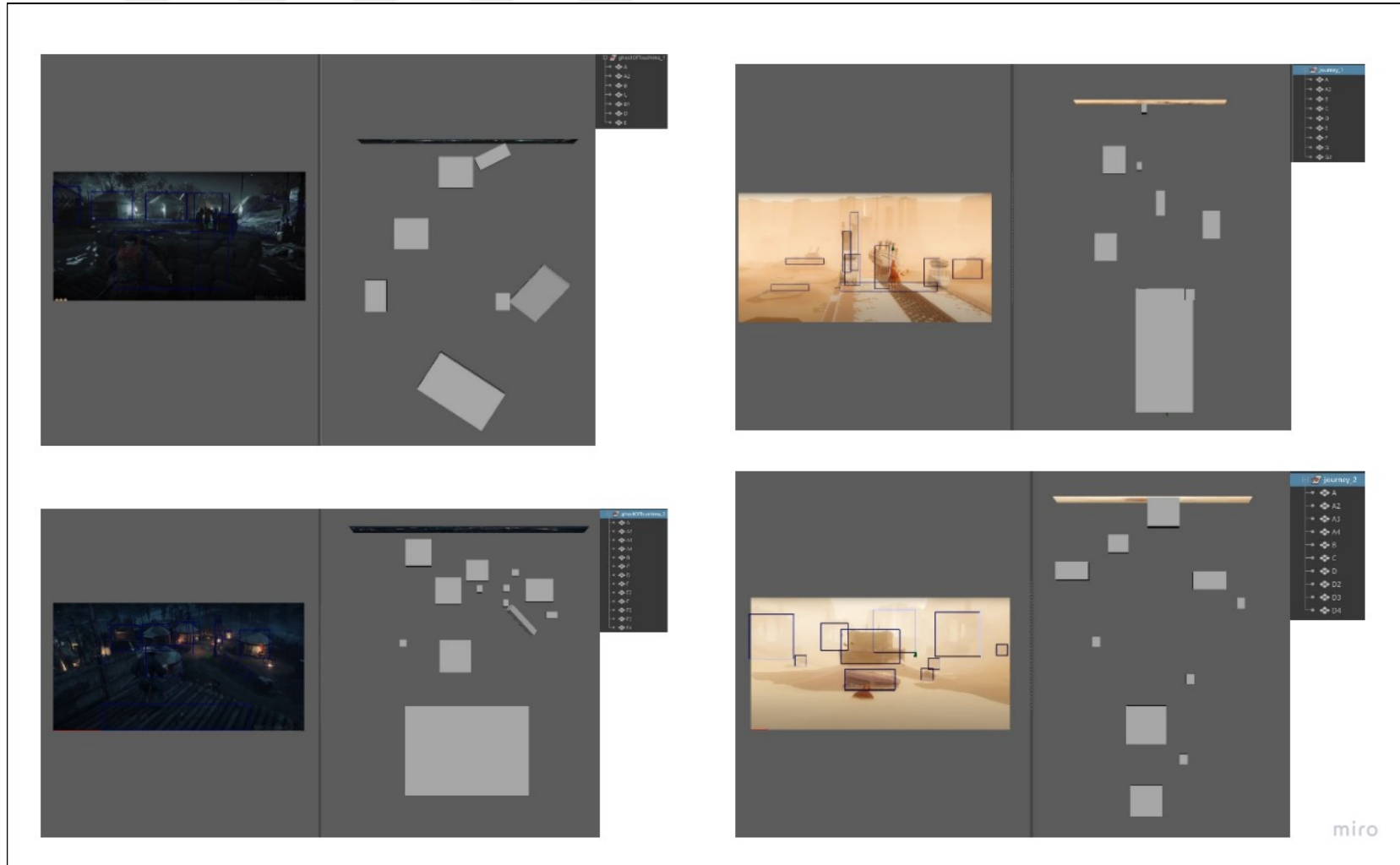


**Figure B.4:** The figure shows the representing & remodeling process of the game scenes Ghost of Tsushima 1, 2 and Journey 1, 2.

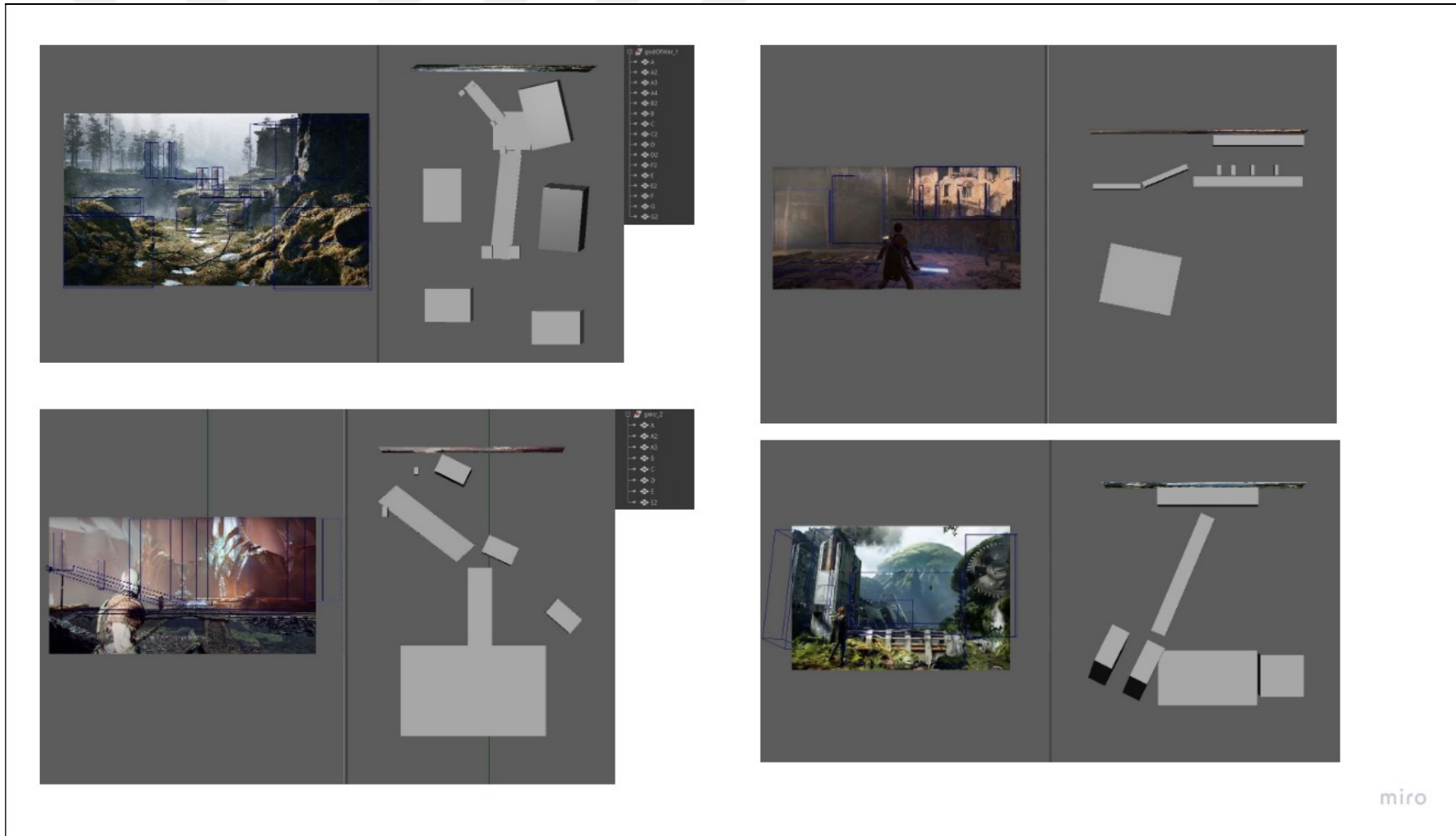


**Figure B.5:** The figure shows the representing & remodeling process of the game scenes God of War 1, 2 and Star Wars Jedi: Fallen Order 1, 2.

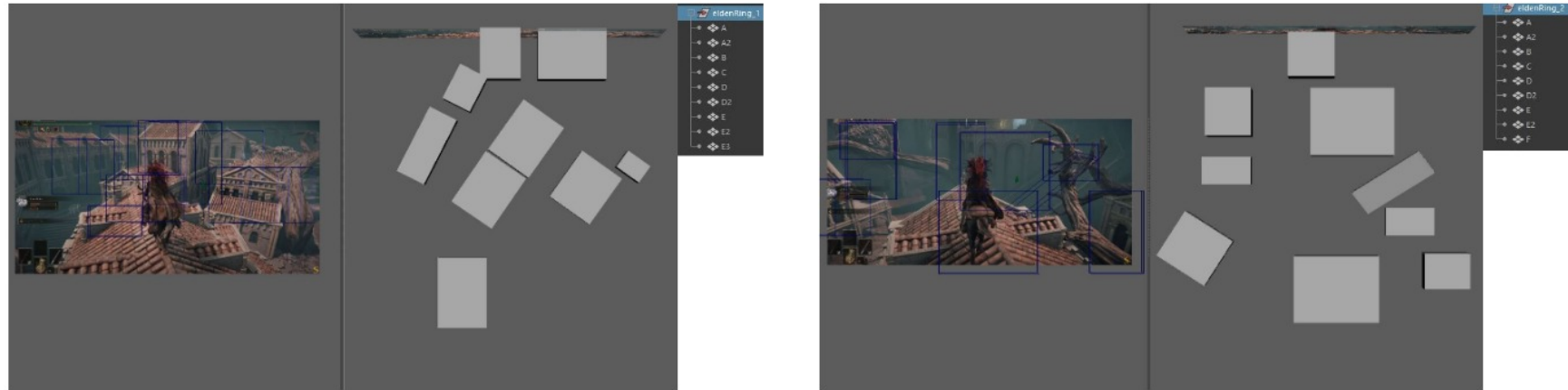


**Figure B.6:** The figure shows the representing & remodeling process of the game scenes Elden Ring 1, 2.



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### PUBLICATIONS, PRESENTATIONS AND PATENTS ON THE THESIS:

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### OTHER PUBLICATIONS, PRESENTATIONS AND PATENTS:

- **Tan, E.,** Güneş, M., Balci, O., Arman, P., (2021). Ekstrem Koşullara Dayanıklı Mobil Modüller için Mekan Organizasyon Algoritması.