A Method for Decoding and Representing Time in Fourdimensional Spaces via Digital Game Environment

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The search for novel representation method is one of the critical components of the creative design process. Discoveries in science, such as four-dimensional (4D) spacetime, influenced artists and architects. However, existing representation techniques constrained in two-dimensional (2D) sheets for 4D spacetime for representation is evaluated as a limitation of architecture discipline. Currently, digital game environments are the potential mediums of 4D architectural representation. This study aims to decode and represent time as an entity of 4D spaces. Digital game environment provides the needed flexibility for experimenting in 4D space. Therefore, unity game engine and C# programming are used together with computer aided design (CAD) tools to generate 4D representations. 4D representations are based on two different impressions of time dimension as (1) time dilation and (2) distortion of spacetime. While time dilation is represented via motion blur (mB) script, distortion of spacetime is represented via motion trail (mT) script. As preliminary results, metrics of the time dimension in 4D spatio-temporal representations are introduced. Experimental 4D representations produced via Unity game engine and C# programming are presented to discuss the potential of game environments to be the medium of architectural representation.

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Dört Boyutlu Mekanlarda Zamanı Çözümlemek ve Temsil Etmek İçin Dijital Oyun Ortamında Bir Yöntem Önerisi

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Yeni bir temsil yöntemi arayışı, yaratıcı tasarım sürecinin kritik bileşenlerindendir. Dört boyutlu (4B) uzay-zaman gibi bilimdeki keşifler, sanatçıları ve mimarları etkilemiştir. 4B uzay-zaman fikrinden etkilenen bir mimarlık için iki boyutlu (2B) paftalarla sınırlandırılmış mevcut temsil teknikleri, bu disiplininin bir sınırlaması olarak değerlendirilmektedir. Günümüzde, dijital oyun ortamları 4B mimari temsilin potansiyel araçlarıdır. Bu çalışma, zamanı 4B mekanların bir bileşeni olarak deşifre etmeyi ve temsil etmeyi amaçlamaktadır. Dijital oyun ortamı, 4B uzayda yapılacak temsil denemesi için yeterli esnekliği sağlamaktadır. Bu nedenle, Unity oyun motoru ve C# programlama, 4B temsiller oluşturmak için bilgisayar destekli tasarım araçlarıyla birlikte kullanılmaktadır. 4B temsiller, (1) zaman genişlemesi ve (2) uzay-zamanın bozulması olmak üzere iki farklı zaman boyutu izlenimine dayanmaktadır. Zaman genişlemesi hareket bulanıklığı (mB) betiği ile temsil edilirken, uzay-zamanın bozulması hareket izi (mT) betiği ile temsil edilmektedir. Ön sonuçlar olarak, 4B uzay-zamansal temsillerdeki zaman boyutunun ölçütleri tanıtılmıştır. Unity oyun motoru ve C# programlama yoluyla üretilen deneysel 4B temsiller, oyun ortamlarının mimari temsil aracı olma potansiyelini tartışmak için sunulmuştur.

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1. INTRODUCTION: ARCHITECTURAL REPRESENTATION AND THE FOURTH DIMENSION

The creative design process contains the development of novel representation methods as critical components of architecture. Drawing has been the primary representation method of architectural designers (Evans, 1997). Architects used drawing for intellectual investigation to represent both tangible and intangible values of a design project. However, conventional representation methods have been expanded to realize or experiment with the conceptual ideas and persist as an integral part of architectural practice (Riahi, 2017). Architects (Şentürer, 2022), as well as artists (Henderson, 2018) in the last century, responded to the discoveries in science such as four-dimensional (4D) spacetime in their works.

The universe has three spatial dimensions and one temporal dimension, so it is called 4D spacetime. People are three-dimensional (3D) organisms and need 4D entities like motion and distortion to perceive the fourth-dimension–time. Architects, too, have been concerned with design problems in 3D space, in parallel to the scientific developments about 4D spacetime made them to consider time dimension in their design projects (Duclos, 2016). Comprehension of temporality in architectural projects was widely undertaken in the past, including well-known examples of the post-situationist era like Walking City and Instant City by Archigram, Diagonal Park by Miralles, Parc de La Villette by Tschumi, etc. They mostly represented their ideas on temporality through 2D drawings made by various methods. Storyboards in eye-level projection, exploded perspectives in axonometric projection, diagrams and inkblots in top-down projection were some of them. However, these representation methods could not reflect their 4D scenarios and underlined limitations of architecture discipline related to the representation (Duclos, 2016: 155).

In the past fifty years, notably, Zaha Hadid as a pioneering architect and artist had interpreted new systems of projection, to plan her complex thoughts about architectural forms, space and time, as well as the relationships between them (Woods, 2008). She widely used distorted perspective to represent fragmented and animated bits and pieces of buildings and landscapes in her conception of the physical environment. Her uncommon representation methods, said to be influenced by the avant-garde artists, eventually had been built in Vitra Fire Station (VFS) project. (**Figure 1.1**) It must be stated that the avant-garde artists influencing Hadid in her architectural representations had expressly concerned the fourth-dimension (Henderson, 2018). Beyond the notional 4D entities, there are clear visual indications: (a) a curved skyline, (b) distorted shadows casting on a spherical ground rather than a flat one, and (c) architectural objects predicted to be deformed by movement (**Figure 1.2**).

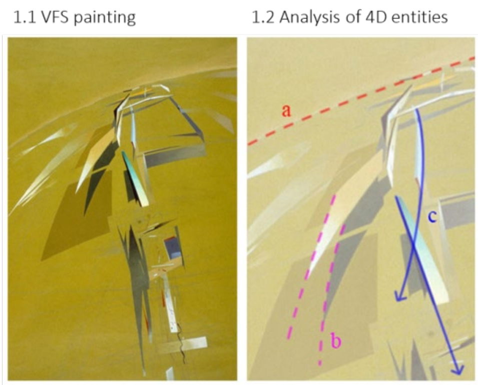

Figure 1: VFS painting by Hadid (1.1) and analysis of visual 4D entities in VFS (1.2).

Hadid's representations considering movement and distortion recall the sketches by Leonardo da Vinci, who uses the movement for exploring the form, context and relationship between them (**Figure 2**). The blurred parts of the object in motion and trails of movement in the sketches indicate how he goes back and forth, how he iterates, in his creative process for designing monumental sculptures (Erhan, 2022).

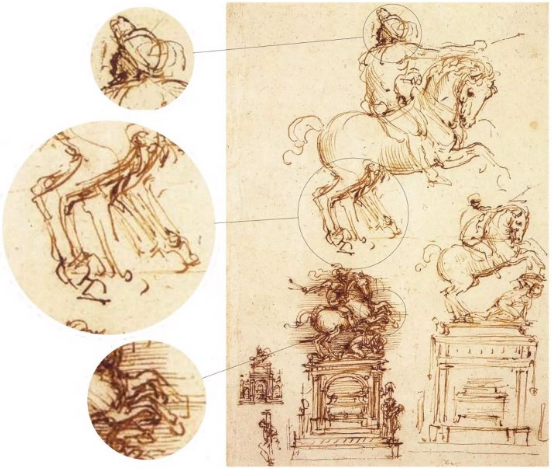

Figure 2: (on the right) Sketches of Leonardo da Vinci for a bronze statue, (on the left) Erhan highlights the explorations in sketches (2022).

Entities like *motion* and *distortion* can be considered as a part of 4D forms of architectural representations. The metrics used for representation of architectural objects in a 3D environment include dimensions of length (x), height (y) and width (z). The metrics for time (t) are usually not considered, so tools and methods for representation of 4D spacetime have remained intuitive. Similar to the techniques like photography and filmmaking, digital game environments can support architectural design process for representational purposes. Digital games are rule-based representations and interactions beyond spoken word, writing, images, or moving pictures (Bogost, 2007). Game spaces integrate representations of architecture, photography and cinema with computer programming.

There is an opportunity that digital game engines can be integrated with the building information modelling (BIM) software to model and evaluate cultural, social and experiential structures, besides spatial components, in an architectural environment (Pearson, 2020). Game environments propose an alternative future for architects living in the period of computational design as a part of technological determinism. Games do not declare that traditional drawing as a method of representation took a back seat with the spread of digital ones. Contrarily, their representational nature is formed by both artists and programmers (Pearson, 2016). They have also a convenience of speculating and experiment in 4D space embodied in a virtual environment with computational rules. Intangible layers that the games allow to represent, especially the experiential ones, show that the temporality and time dimension can be represented by encoded rules and visual elements (Youkhana & Pearson, 2021).

Digital game environments can be considered as the mediums of 4D architectural representation. They allow modelling 4D spacetime objects (Ohori et al., 2017) and visualizing higher dimensions (Cavallo, 2021) based on the branch of n-dimensional geometry in Mathematics. Time plays a supporting role in visualization and modelling in n-dimensional geometry, as well as artistic and architectural representation (Henderson, 2018). It helps geometer or artist to represent an object's total dimensionality via moving physically or mentally.

In this study, time is a conception to be decoded and represented for 4D architectural projects. In line with the state of time concept in domains of mathematics, physics and arts, the methodology of this study uses the Unity game engine and C# programming language, together with CAD tools, to achieve a measurable output of the time dimension within architectural representation. Since the creative design process should be expressive and incremental (Simon, 2001 and Dietrich, 2004), the proposed method supports this process that includes metrics and programming of time conception in architectural design projects.

2. METHODOLOGY: DECODING AND REPRESENTING TIME

Architectural representation can be applied for 4D spacetime through digital game environment. As a part of the methodology, two critical components are investigated initially as *metrics* and *programming*, to represent time as an entity of 4D spaces. While metrics of time define the fourth-dimension, programming time is studied to get a visual outcome of time dimension through defined metrics.

The methodology comprises two stages, in which *distortion of spacetime* and *time dilation* are investigated by the use of Unity game engine and C# programming languages. Critical terms and concepts related to the metrics of time are introduced initially. Then, the process related to the programming time will be presented.

2.1. Metrics of Time

The metrics of time (t) dimension had to be defined before they could be represented as the metrics of length, height, and depth (x, y, z) in the third-dimension. Then the 4D spacetime (x, y, z, t) can be speculated as the context of an architectural object. An object must be described in not only length, height, and depth (3D) but also time (4D) based on the Relativity Theory. There are no more points independent on time, as it could be in the 3D space. Space and time are merged into a 4D continuum, named Minkowski spacetime. The dimensions of (x, y, z, t) are events. The points of the 4D spacetime are events, not geometrical points as in the 3D space . To describe an event in 4D spacetime, it must be known where it happens as well as when it happens. Moving through the space requires moving through (Foschini, 2017) the time. Einstein's Relativity Theory (1920), and his former professor, Minkowski's mathematical model (1920), show the experience of changes in space and time for an observer. The observer experiences time dilation and length contraction when it moves through the space. The faster it moves through the space, the slower it moves through the time. It also experiences that the spatial distances (x, y, z) appear to be shorter along its direction of motion.

Time is relative to the observers' reference frame, not simultaneous, since they usually have different frames in 4D spacetime. They can speak of simultaneity if they meet each other at the same spacetime coordinates (x, y, z, t), that means being on the same coordinates location and the same time coordinate, so being in the same event that is not possible for objects. However, time seems to be simultaneous in practice because people need to agree on a uniform time in daily life. It is derived from a kind of 'mean second' by using geoids as reference frames to ensure time dilation effects caused by Earth's rotation (Bauch, 2021). If such a time measurement valid in all locations is desired to be made, the fourth coordinate, which is time in spatio-temporal system, must always be defined. Similarly, referential frames are set for also representing an architectural object in motion. Despite time is concerted and effects of time dilation are reduced in daily life, time dilation can be illustrated in architectural representation that is a dominant part of the design process. The representation of time is expected to be relative too, because architects as observers have their own standpoint and ideas to be spatialized in 4D spacetime.

Motion itself is not a metric for representing time. It is the referential frames that implement an observation of time and its effects. The geometry of spacetime is dynamic and its evolution must be detected together with matter. The principle of background independence defines the absence of an externally prescribed geometry. With the need for a generalization of the Einstein's background independence principle, the theory of Loop Quantum Gravity (LQG) emerged (Thiemann, 2005). In LQG, the geometry is intensified into one-dimensional structures that are arbitrarily complicated graphs, at each instant of time. As a result, a spin network describes the quantum state of space at a certain point in time. A space that is distorted and curved by time is represented by a generic spin network. If the matter, that must be determined with the geometry of spacetime, is considered as the architectural object, the motion would be the evolution of matter and spacetime. The architectural representation is a sort of image of spatial network showing the evolution and its effect, that is the distortion of spacetime at a certain state.

In brief, “time dilation” and “distortion of spacetime” are the impressions decoding the metrics of time. Time dilation is the one defining the metric of “frame” derived from Relativity Theory in macro-scale. Distortion of spacetime is the other one characterizing the metric of “instant” got from LQG theory in micro-scale. The fourth-dimension can be distinguished via *frames* or *instants* being set for measuring time represented in architectural projects.

2.2 Programming Time

Time dimension is programmed via C# language to generate a measurable visual output. The fourth-dimension, time, is assigned to relevant variables in two different impressions based on (1) time dilation and (2) distortion of spacetime, which determined the metrics. The programming for generation of architectural representations in game engine is based on these two impressions of fourth-dimension. Two different open-source scripts in the C# programming language that works with the types of variables like float, integer, boolean, etc. were selected to run. Scripts are the series of instructions for the game engine, conducted in a particular order, for example, creation of visual effects when movement is defined for an object. While motion blur (mB) script (GitHub, 2017) decodes the time dilation, motion trail (mT) script (Unity Asset Store, 2011) decodes the distortion of spacetime. The scripts are produced for visual effects that are an important part of film production, photography and game production. They can smoothly be used for architectural representation, as the game environments conjoin representations of architecture, photography and cinema representations with computer programming.

2.2.1. Motion Blur (mB) Script

The script has two data types: boolean and integer. Animated movement added to user input is the boolean data in this script. The value must be true, so a movement must be animated for the architectural object. Shutter angle (A) is an integer data of mB, defining exposure time during the frame interval. It must be a value between zero and three-hundred-sixty (**Figure 3**). It is a term for cinema, the identical one is the "shutter speed" in photography. The greater A value is, the more blurred motion.

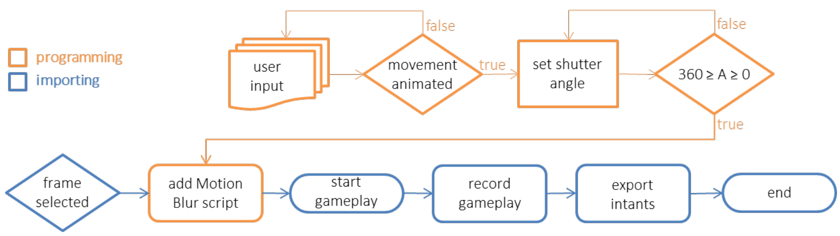

Figure 3: Flowchart of Motion Blur (mB) Script.

Movement must be existed to represent time. Detection of the fourth-dimension (t) seems impossible when the spatial coordinates (x, y, z) of an object are stable because the space and time are treated together. Whenever the object moves, time dilation and length contraction become measurable through the frames demonstrating mB script.

2.2.2. Motin Trail (mT) Script

Boolean and integer data types constitute the script. A movement animated value must be true to run the script. Emit time (t_{emit}) and lifetime (t_{life}) are integers of mT, that is generating the trace of an architectural object in motion (**Figure 4**). While t_{emit} determines the duration of trace being generated, t_{life} specifies the length of trace. Trail particle, trail mesh and child objects are among the layers used for render in the Unity game engine.

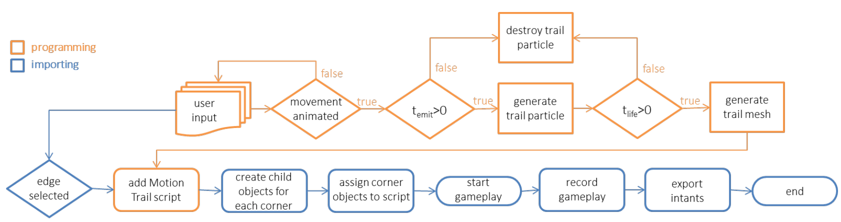

Figure 4: Flowchart of Motion Trail (mT) Script.

Recognizing and tracing the fourth-dimension (t) is possible in the certain states during change in spatial coordinates (x, y, z) of an architectural object. Distortion of spacetime and spatial network evolved by the movement become observable through the instants illustrating mT script.

In summary, the scripts are to provide a measurement by using the metrics of frames and instants as well as an observation of time dilation and distortion of spacetime.

2.3. Generating 4D Architectural Representations

Generation of 4D representations are used to test programming of time and present measurable visual outputs. Architectural object in motion was modelled via the Probuilder software in Unity game engine for the representation experiment (**Figure 5**). Other software that allows an output in Autodesk Filmbox format (.fbx) can be used for modelling and exported to the Unity game engine. The architectural object was an abstract representation in form of a 3D-model. It became 4D when the movement was involved in the representation. Its fourth-dimension, time, is visualized via the proposed methodology.

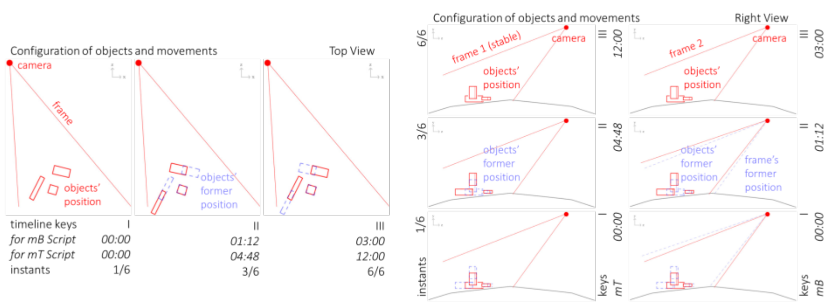

Figure 5: Configuration of architectural objects in motion.

A representative architectural object was animated in Unity game engine. Speed of the animated movement is faster (3 secs.) to catch apparent visual effects via mB script while it is slower (12 secs.) for mT script. Animations from outer sources can be also exported and added as a component to the object in the game engine. There are also components of mB and mT scripts that were explained under the title of Programming Time. The mB script was added as a component on camera, while the mT script was added to the objects. The movement of objects and camera frames are described in **Figure 5**. to observe the visual effects of each script clearly, mB script (blur effect) was deactivated when representations were generated through mT script (trail effect), and vice versa. Although the measurable outputs are not expected, the ones that both scripts were activated were also generated in the end.

Recalling the metrics of time, to compose the representation of time dilation and distortion of spacetime, the gameplays of both frames (1 and 2) are recorded. The records are divided into the instants (from 1 to 6) of equal time intervals. Thus, outputs of two different scripts (mB and mT) can be clearly evaluated by using the metrics of frames and instants (**Table 1**).

Table 1: Metrics and programming of time.

Dimensions	Metrics	Type	Entities	Effects
x y z	length height depth	spatial	body	time dilation, length contraction (gravitation)
t	instant, frame	temporal	movement	distortion of spacetime

The representative architectural object that was produced for testing the proposed methodology is a spatial entity–body. Its animated movement is a temporal entity. The body in motion defines a 4D configuration. The proposed method starts with recording the configuration. Then, by exporting instants, deconstructs it through its dimensions that are affected by the temporal entity–movement. The effects can be summarized as deformations of body and movement. The study decodes these deformations via the metrics of t dimension–instants and frames. Thus, it proposes and tests a novel method of architectural representation that can be applied for exploring and iterating spatial organization and form finding process (**Figure 6**).

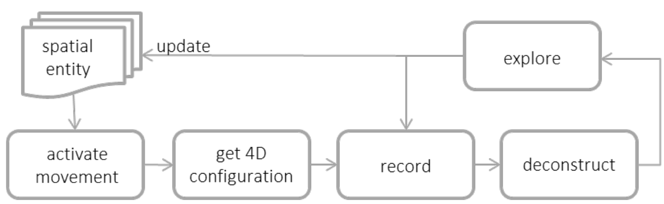

Figure 6: Application of the proposed method.

3. RESULTS AND DISCUSSIONS

Throughout this study, 4D spacetime, particularly the time dimension, is explained and investigated within architectural design discipline in relation to gravitational theories of physics in micro and macro scale. Time dilation and distortion of spacetime are the phenomena being used for decoding the fourth-dimension of space. Results from decoding and representing time are presented below.

3.1. Representation of Time via Instants and Frames

The proposed methodology in this study was experimented on the configuration of moving architectural object. Experiment comprises two steps. The first step uses mT script for generating 4D representations, revealing the distortion of spacetime. The second one uses the mB script for generating 4D representations, expressing the time dilation.

In the first step, frame 1 and 2 have the same visual outputs in terms of distortion in architectural objects and the spatial relation between them (**Figure 7**).

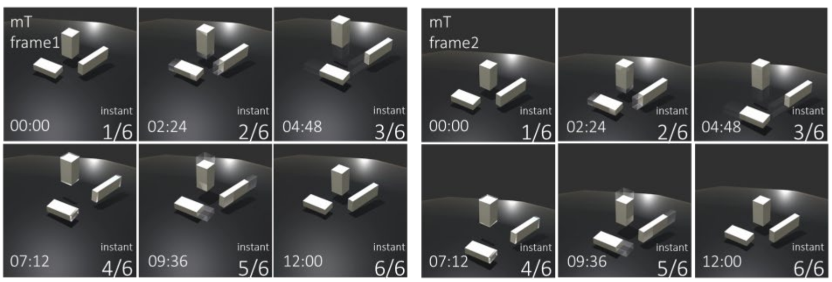

Figure 7: First step of the test: Generation of 4D representation by using mT script to detect distortion of spacetime through the instant metric.

Thus, it suffices to analyze the outputs of this test only through the instants. The spatial network, which illustrates the relation between architectural objects, distorted in sequential instants in both frames (**Figure 8**). The spacetime defined by architectural objects was distorted by temporal (4D) entity, that is the movement. Meanwhile, the spatial dimensions (x, y, z) have not changed among the instants.

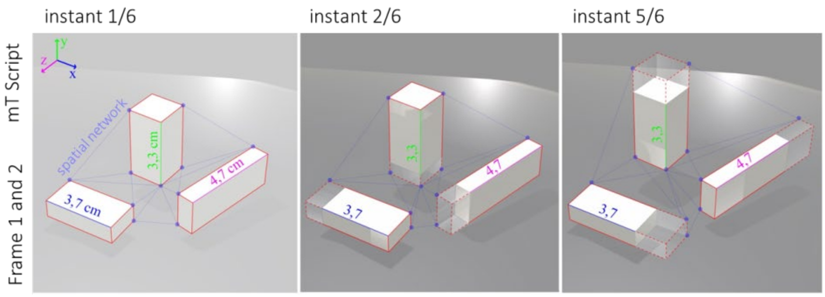

Figure 8: Comparison of the distortions in objects and spatial network through the instants.

Generation of representations that emphasize the distortion of spacetime by movement guides description of 4D spatial relations between architectural forms. Novel methods can be derived from 4D tools to represent the elaborated conception of designers on the spacetime they work on. They can use the 4D entities, such as movement through the spacetime, and their effects, the distortion caused by movement, to express the design process of architectural forms in relation to each other.

In the second step, the outputs of frame 1 and 2 are have differences in terms of distortion in dimensions of architectural objects and the spatial relations (**Figure 9**).

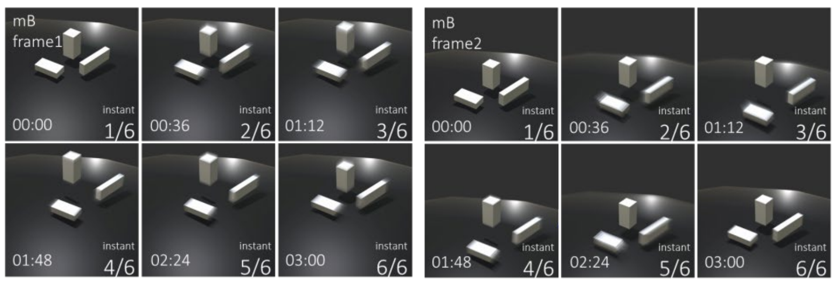

Figure 9: Second step of the test: Generation of 4D representation by using mB script to detect time dilation through the frame and instant metrics.

Therefore, outputs are analyzed through both frames and instants. All the three objects were blurred, their apparent solid parts were reduced, meaning lengths of the spatial dimensions toward movement were contracted at all instants in frame 1. Meanwhile, the object followed by the moving frame was not affected by motion blur, as if it was stationary at any instant in frame 2 (**Figure 10**). This results from Frame 1 was not moving while Frame 2 was moving by following the vertical object.

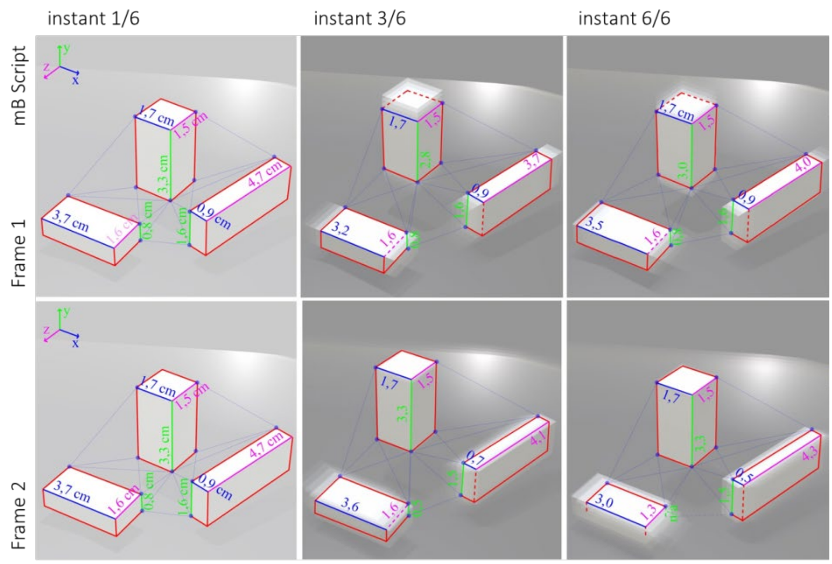

Figure 10: Comparison of the distortions in objects and spatial network through the instants and frames.

In frame 1, length contraction as a gravitational effect of bodies (objects) appeared only on dimensions toward movement for each object. It appeared in the y axis besides the movement direction of objects in frame 2, because the frame was also moving in the y axis. (**Figure 10**) Thus, the objects other than the one followed by frame, looked like they move on two axes. The frame 2 provided a relative way of representing the moving bodies or architectural forms.

The effects of time in the test using mB script in frame 1 and 2 differed from the one using mT script. The distortion of objects and spatial network at instant 4/6 looks similar in both of the tests. At instant 5/6, the difference is apparent between two tests (see **Figure 11**). The difference stems from the logic of the scripts. While mB script is added on camera, mT script is added to the objects and they create visual effects accordingly. Thus, the distortion of spatial networks at equal instants in two tests can vary.

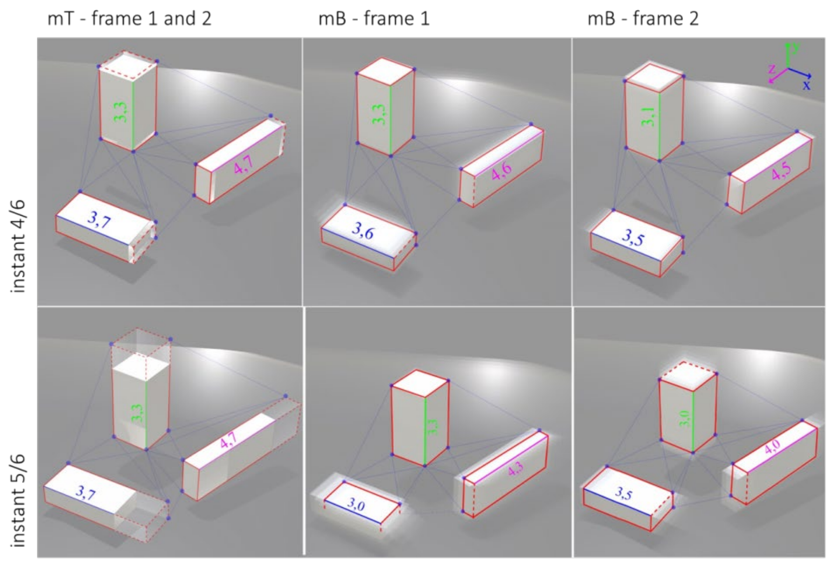

Figure 11: Comparison of the distortions in objects and spatial network through the instants and frames of both tests using mT or mB script.

The distortion of spacetime and variation in these temporal effects can become 4D tools for developing novel representation methods. Generating representations by using mT script that are independent from camera in game environment, observer or user in physical environment, can narrate a design process describing the architectural forms and spatial relations between them. Generating representations by activating mB script that are linked to the camera can demonstrate a narrative, including users and their perception of the architectural environment proposed by the designer. In both tests, participation of the designer in outputs of digital representation methods is increased via the game environment.

3.2. Case Study: An Early Representation of the Fourth-Dimension

Zaha Hadid's painting of VFS is examined by this study because it is an early architectural representation of 4D spacetime. There is visual evidence of fourth-dimension in this case, besides the movement and fragmentation. (**Figure 1.2**) The 4D entities, like curved surfaces, motion and distortion, are intuitive in this representation, yet they can be reproduced via proposed methodology in this study. To test the proposed methodology, an abstract 3D model of the VFS project was created via Probuilder in Unity game engine according to the dimensions of physical building (Zaha Hadid Architects, 1993). Some of the apparent 4D entities, like the curved skyline and spherical ground, were represented by creating a sphere object. A model that was created in other types of geometric modelling software and saved in filmbox (.fbx) format is also possible to be imported to the game engine. Objects were colored according to the original painting by adding plain materials as components. Thus, the motionless state of the 4D representation has been completed.

Architectural objects were animated to represent the 4D entities, distortion and motion, by using mT and mB scripts together. A movement is animated for also the camera (**Figure 12**). Both of the script components, mT and mB, were activated in recording of this representation because Hadid's painting includes both visual effects–deformed spatial dimensions and traces of movement. An output that is identical with original painting is not expected because the exact movement imagined by Hadid is unknown. This implementation shows that a digital methodology can be adopted to generate not only explanatory representations of architectural works but also exploratory ones.

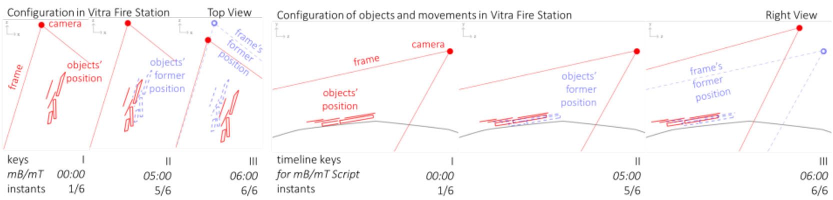

Figure 12: Configuration of objects and movements in VFS.

3.2.1. Generation of 4D Representation via Game Environment

The proposed methodology in this study applied to VFS project as a case study (**Figure 13**). The case study aimed to demonstrate an alternative digital representation methodology that can investigate 4D spacetime. Both of the script components, mB and mT, were used in same recording to reproduce intuitively represented 4D entities via conventional methods in original painting by Hadid.

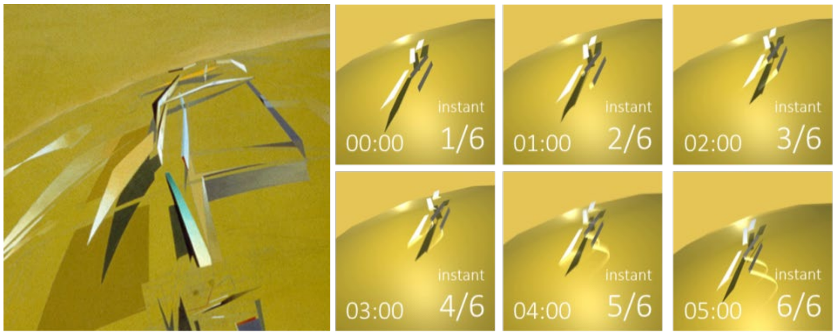

Figure 13: Application of the proposed methodology: (on the right) generation of digital 4D representation of VFS by using mB and mT scripts together to reproduce the intuitive 4D entities in (on the left) the original painting.

Generated digital representations are not identical to the original one, but they are adequate for revealing a digital alternative for a unique representation method. At the instant 1/6, the dimensions from each spatial axis (x, y, z) and the spatial network between two elements were selected to examine (**Figure 14**).

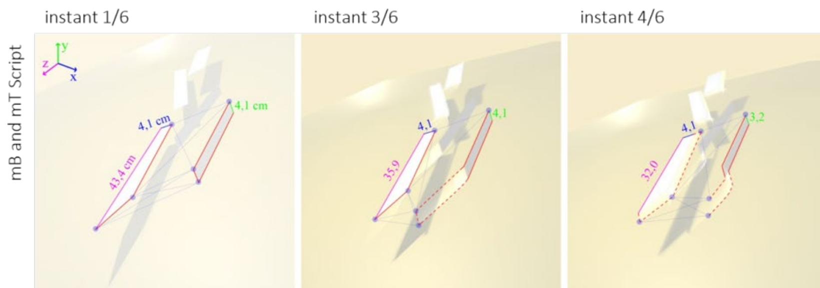

Figure 14: Selected instants of VFS Project configuration.

An effect of fourth-dimension, length contraction of spatial dimensions on the direction of movement, is evident at instants 3/6 and 4/6. The object moved on the z axis from instant 1/6 to 6/6, so the length of z dimension was contracted. The camera also moved at instant 4/6 on the y axis, so length of the y dimension was contracted. Among the instants, the spatial network and geometry of surfaces, too, are distorted by the movement that is a 4D entity.

Representing the distortion caused by movement as a 4D entity can open a window for creative design process that explores the ground, skyline and architectural forms and the relationship between them in 4D spacetime. Implementing those representations via digital methods offers both novel and iterative outputs, which carry intellectual design ideas beyond only visualization. Hadid uses spatial mapping and projective geometry to represent form and context in motion in her studies (Schumacher, 2004). She represents the seizing and designing the surrounding context in the VFS project through concrete and glass panels in motion that are hanged at a certain instant (Hiesinger, 2011: 58). Iterating the proposed and tested representation method can be a digital alternative workflow. Generated representation outputs can contribute to the exploration of form, context and the relationship between them in the creative design process.

3.3. Conclusion

Architectural representation is a critical matter in the intellectual investigation of a design project, and digital game environments are potential 4D tools for it. Throughout this study, a digital representation methodology was proposed for not only visualizing a project but also to represent intellectual investigations about 4D spacetime involving to the project. 4D forms of architectural representations, including motion entity and distortion effect, are detected and evaluated in this study. Additionally, parameters of 4D configurations can be tested via proposed method in digital game environment (Table 2).

Table 2: Parameters of a 4D configuration as indicated in the Figure 6.

Process	Parameters	Explanation
activate movement	transformation	basic geometric transformations like scaling, rotation, translation, and shear
	duration	duration of the transformations from starting to the end
deconstruct	frames	frame of observer recording the configuration and
	instants	instants from defined time intervals of the recordings

Through the digital game environment, 4D tools became accessible and contribution of designer was increased to use digital methods to represent a project rather than only visualizing it. The methodology in this study was tested by architectural objects in Unity game engine may become a tool for supporting creative design process for a future study. The established method could have been improved in terms of implementations and tests for a defined design brief. A broader perspective for using game engines for exploratory representations of architectural forms and contextual relations, rather than simulating occupant behaviours, was presented (Figure 15).

Figure 15: Framework of exploration through proposed method.

Conception of spatio-temporal world and its impressions affected architects in terms of how they think and design. Thus, the study pursued the conception of time in architectural representation in relation to the science and arts. Intuitive time conceptions in the architectural representations were decoded based on laws of physics and visually represented via an iterative method that was implemented in the digital game engine.

References

Albert, E. (1920). Time, Space and Gravitation. In *Science*. New York; The Science Press.

Bauch, A. (2021). *How time is made*. Einstein Online. Retrieved February 5, 2023, from https://www.einstein-online.info/en/spotlight/how-time-is-made/

Bogost, I. (2010). *Persuasive games: The expressive power of videogames*. MIT Press.

Cavallo, M. (2021). Higher dimensional graphics: Conceiving worlds in four spatial dimensions and beyond. *Computer Graphics Forum*, *40*(2), 51–63. https://doi.org/10.1111/cgf.142614

Dietrich, A. (2004). The Cognitive Neuroscience of Creativity. *Psychonomic Bulletin & Review*, *11*(6), 1011–1026. https://doi.org/10.3758/bf03196731

Erhan, H. (2022). *Special Topics in Game Design & Development: Creativity and Developing Computing Technologies* (Class Notes). Istanbul Technical University, Master's Program of Game and Interaction Technologies.

Evans, R. (1997). *Translations from drawing to building*. MIT Press.

Foschini, L. (2017). Yet another introduction to relativistic astrophysics. https://doi.org/https://doi.org/10.48550/arXiv.1703.05575

GitHub. (2017). *Motion Blur post-processing effect for unity*. Retrieved February 5, 2023, from https://github.com/keijiro/KinoMotion

Henderson, L. D. (2018). *Fourth Dimension and non-euclidean geometry in Modern Art*. MIT Press.

Hiesinger, K. B. (2011). Zaha Hadid: Form in Motion. *Philadelphia Museum of Art Bulletin, 4*, 14–60. http://www.jstor.org/stable/41501092

Minkowski, H. (1920). *Raum und zeit*. Leipzig, Berlin; B. G. Teubner.

Ohori, K. A., Ledoux, H., & Stoter, J. (2017, June 30). *Modeling and manipulating spacetime objects in a true 4D model*. Journal of Spatial Information Science. Retrieved February 5, 2023, from https://josis.org/index.php/josis/article/view/78

Pearson, L. C. (2016). Architectures of Ironic Computation: How videogames offer new protocols for architectural experimentation. *Inflection*, *3*. Retrieved February 5, 2023, from https://discovery.ucl.ac.uk/id/eprint/1550096/

Pearson, L. C. (2020). A machine for playing in: Exploring the videogame as a medium for architectural design. *Design Studies*, *66*, 114–143. https://doi.org/10.1016/j.destud.2019.11.005

Duclos, I. P. (2016). *Contingency in Post-Situationist Architecture* (Doctoral Dissertation). *Archivo Digital UPM*. Retrieved February 5, 2023, from https://doi.org/10.20868/UPM.thesis.44442

Riahi, P. (2017). Expanding the boundaries of architectural representation. *The Journal of Architecture*, *22*(5), 815–824. https://doi.org/10.1080/13602365.2017.1351671

Simon, H. A. (2001). Creativity in the Arts and the Sciences. *The Kenyon Review*, *23*(2), 203–220. http://www.jstor.org/stable/4338222

Schumacher, P. (2004). *Digital Hadid: Landscapes in Motion.* Basel: Birkhäuser.

Şentürer, A. (2022). Designing through Archi-Cine Sections/Sectional-Montages. In *Trans Studio*. 64–81. Yem.

Thomas, T. (2005). *The Fabric of Space: Spin Networks*. Einstein Online. Retrieved February 5, 2023, from https://www.einstein-online.info/en/spotlight/spin_networks/

Unity Asset Store. (2011). *Trail Particles/effects*. Unity Asset Store. Retrieved February 5, 2023, from https://assetstore.unity.com/packages/tools/particles-effects/melee-weapon-trail-1728

Woods, L. (2008). Drawn into space: Zaha Hadid. *Architectural Design*, *78*(4), 28–35. https://doi.org/10.1002/ad.702

Youkhana, S. & Pearson, L. C. (2021). The Allegorithmic Utopia of Videogame Urbanism. In R. J. Hyde & F. Filippidis (Eds.), *Intelligent control: Disruptive technologies*. essay, RIBA Publishing.

Zaha Hadid Architects. (1993) Vitra Fire Station - Zaha Hadid Architects. Retrieved February 5, 2023, from https://www.zaha-hadid.com/architecture/vitra-fire-station-2/