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HOW DO COGNITIVE MAPS CHANGE IN TIME?
Searching the Effect of Time on Cognitive Maps through Spatial Configuration and Long Term Memory Theories

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ABSTRACT

Throughout the human experience, various memory systems code the environmental context with selective processes and transfer these coded information to the long term memory. Long term spatial memory relates merely to the spatial information; and is studied through such concepts as schema, schemata, mental map or cognitive map in various disciplines. Many theories indicate that cognitive maps are the representations of real space ensuring the individual a total understanding of his/her environment. They are not reciprocal to real space and they constantly develop a multidimensional structure over topological relations where every point is connected to the other points like a net. Moreover, autobiographical memory researches revealed that recalling performance of an individual is dependent on the factors of age, life period and the elapsed time after the recalled experience. On the basis of these facts, two basic questions are asked: (1) if age and/or time are significant factors over the ongoing restructuring of the cognitive maps, and (2) how can we investigate and reveal the effect of these factors analytically?

In this paper, the time factor on the structuring of cognitive maps is investigated through the participant's age and the spatial configuration of the represented space. Inspired from Kim and Penn's (2004) study, a methodology is designed over the spatial syntax analysis of the cognitive maps. The research group is composed of 52 male graduated students of a prominent secondary school, whom belong to three age ranges (23-39, 40-65 and 65-75) that regard to the three adulthood life periods. In order to collect the cognitive data, every participant is asked to draw a sketch of the ground floor of his school building in two successive sessions. Each cognitive map is analysed through its convex map (1) to define the number of recalled spatial units in each session, and (2) to calculate the syntactic values of depth, mean depth and syntactic step. The correlations show strong negative relations between the age and syntactic values, and between the age and contents of spatial units. These results approve the memory theories and show that age and time are significant factors over the restructuring of cognitive maps. In addition to that, this study presents that space syntax analyses are adaptive tools for spatial memory and autobiographical memory researches, most particularly for the one's that focuses on the time factor.

KEYWORDS

Architecture, Cognition, Cognitive Map, Spatial Memory, Spatial Configuration

1. INTRODUCTION

Among the many characteristics of the human kind distinct from animals, the ability to store countless long term memories concurrently and permanently can be regarded as the most significant. We learn and never forget that a lion is dangerous, our house is on the North, snow will fall in winter or our teacher has got glasses. The mental system that develops, stores, relates and uses these information is called 'memory'. In the simplest term, our memory enables us to make a mental time travel to our past, to remember what to do and how to do in our daily life and to use the knowledge of our previous experiences when necessary.

In this paper, the time factor on human memory is researched through spatial memory and its representation as a cognitive map. Regarding this scope, the theoretical background is focused on the basic characteristics of human memory, the spatial memory, the cognitive map concept and their relation with time factor.

Human memory has been theorized through different memory systems. Atkinson and Shiffrin's multiple memory system model called Modal Model is one of them that comprises many characteristics of the other models in 1960's and it still represents the basic characteristics of the current models (Goldstein, 2011). It has three basic components as Sensory Memory, Short Term Memory and Long Term Memory that code, store and use the information obtained from the environmental context through selective processes. It also includes the control operations (such as attention, encoding, recall, rehearsal) that transmit information between these components. Along these, short term memory concept was the one that has been improved and today Baddeley's Working Memory model is widely accepted instead.

Sensory Memory is the entrance door of memory where the environmental data is collected by human senses (defined as visionary, auditory, olfactory, gustatory, tactual, muscular, organic and vestibular), in which visual and auditory senses are approved as the primary senses (Ozak, 2008). It stores massive information of environmental stimulus in a really short time but on the other hand that information fades away rapidly in seconds (Goldstein, 2011). Working Memory stores a little amount of information for a short time period (for minutes) and has four components. The Phonological Loop and Visuospatial Sketchpad are associated to the primary senses and code information, Central Executive directs the operation of information and Episodic Buffer stores the information. Part of this information in working memory is transferred to the Long Term Memory and the rest of the information gets lost in time.

Long Term Memory is the third and last component of human memory and it codes, stores and recalls information for long time periods. There are two types of Long Term Memory; (1) Explicit Memory, (2) Implicit Memory (Nelson and Fivush, 2004). Implicit Memory has four types of memory -Priming, Procedural memory Simple Classical Conditioning and Nonassociative Learning- that holds and processes general information without a sense of past, an intention or human consciousness (Smith and Kosslyn, 2014). Explicit Memory has two types of memory that can collect the information of recent memories; (1) Episodic Memory stores the memories which we can recall consciously, make us travel back in time and has a spatial context, and (2) Semantic Memory stores general information that is not connected to any spatial-temporal context (Goldstein, 2011). Today, it is acknowledged that these two types of Explicit Memory are working together to support each other and episodic memory is being used to generate semantic memory information (Ryan et al., 2008). Additionally, Autobiographical Memory is also a type of declarative and explicit memory but it is not a defined component of the Long Term Memory model. It includes memories of some specific subjectively/bodily coded experiences in the past that are recalled only from a subjective perspective (Nelson and Fivush, 2004).

In the context of these memory theories it should not be forgotten that human memory is not a recording system. Memory is obliged to be deformed/transformed (Smith and Kosslyn, 2014). Different kinds of this memory reconstructions/distortions are handled under the concept of Source Monitoring in which information from different experiences are used to fill a gap during the recalling of another experience (Goldstein, 2011). Source monitoring error is another kind of memory reconstruction where the source is misidentified by mechanisms such as suggestion, bias or misattribution. Bartlett's The War of the Ghost's experience could be taken as the most basic example in this context and shows clearly that human memory reduces, distorts or transforms the information during the recalling process.

On the other hand, Autobiographical Memory researches revealed many kinds of memory reconstructions depending on the factors of age, life period and the elapsed time after the recalled experience. For instance, the flash memory researches show that the information coded during the experience of an important public event are transformed or go missing when recalled as a memory (Bauer et al., 2012). Many researches within the age range of 12 to 70 also indicate that recent memories are always easier to recall in every period of human lifecycle (Rubin, 2000). In addition to that, researches with adults show that the memories coded in late adolescence and early adulthood periods are more than the other periods numerically (Conway and Pleydell-Pearce, 2000). Also Sebba's (Morgan, 2010) research presents that the childhood memories are reconstructed and reinterpreted to a degree when recalled in adulthood. All these findings and theories clearly show that memory is not a copying device, it is continuously changing, it is not strongly constructed and therefore it is always open to reconstruction.

1.1 SPATIAL MEMORY AND COGNITIVE MAPS

Within this debate, the spatial information in memory has its own theoretical field under the concept of Spatial Memory that involves the Long Term Memory systems in conjunction with the Working Memory systems. In this context, the spatial information is mainly formed with the stimuli coded by Visuospatial Sketchpad which is considered to be activated when the surrounding information is categorized into colour, shape and spatial position (Kokubo et al., 2012); and then transferred to Long Term Memory. The recalling of spatial information from Long Term Memory is defined as Visual Imagery, the ability to create a sensory environment in mind using many mental functions such as perception, memory and thinking. Pylyshyn (Smith and Kosslyn, 2014) propose that visual imagery is similar to linguistic representations and is based on symbolic representations like letters or numbers which are independent from the real object. On the other hand, Kosslyn (Smith and Kosslyn, 2014) suggests that each feature in a spatial representation in mind correspond to a feature of the real object and spatial location is one of these features.

Spatial Memory concept usually defines merely the spatial information, independent from colour, emotions, sounds, etc. It is about objects, their locations and their relationships, which further relates to previously mentioned visual imagery definition of Kosslyn (Smith and Kosslyn, 2014). Still, Kosslyn's prominent research experiments about visual imagery is not adequate to explain all kinds of spatial memory. They are limited to object scale and ignore the oral representation of a visualized space in which a person can represent the memories details more clearly. Theories handling the spatial information in larger scales (such as buildings, urban area or natural environment) and with wider perspective (such as physical attributes or participants) are within various other disciplines such as environmental psychology, architecture, philosophy, geography or urban planning. Among these theories the cognitive map theory is the closest one to spatial memory depending on its focus on the representation of real space in the mind, or in other words in the long term memory.

Cognitive map concept is studied under many other concepts such as Spatial Schema (Gattis, 2001), Mental Space (Tversky, 2003), Cognitive Collage, Spatial Mental Model (Tversky, 1993), Cognitive Space, Spatial Cognition (Penn, 2003) and Schema (Hart and Moore, 1973). Still, there is a consensus on the definition of the cognitive maps as the representations of real space that ensures the individual a total understanding of his/her environment (Kaplan, 1973; Kuipers, 1978). They are structured by organizing the spatial information gained from the environment during an experience or by using spatial information gained from different experiences or other sources of information (Cooper and Lang, 1976). Every cognitive map is unique, not reciprocal to real space, deformed, unstable and open to reconstruction (Downs and Stea, 2011; Kaplan, 1973). They have a multidimensional structure over topological relations where every point is connected to the other points like a net and they are constantly being reconstructed and developed in memory by adding new information from the ongoing experiences.

All of these definitions indicate that cognitive maps are parts of a more complex memory system which correspond mostly to the episodic memory depending on its distinctive ability to store spatial context of an experience. It includes the cognitive processes of acquiring, coding, storing, recalling and decoding of information about relative locations and other spatial attributes (Downs an Stea, 2011). In this respect, cognitive maps can also be considered as memory systems that are obliged to be deformed/transformed and time can be considered as a significant factor on the reconstruction of cognitive maps.

Depending on this theoretical background that combines memory theories with environment and behaviour theories; two basic questions are asked in this research. The first question is if age and/or time are significant factors over the ongoing restructuring of the cognitive maps; and the second question is how can we investigate and reveal the effect of these factors analytically?

Inspired from Kim and Penn's (2004) study, a methodology is designed to answer these questions through a person's age and the spatial configuration of the space that he/she remembered. The data regarding to the remembered space is collected through the syntactic analysis of cognitive maps and its relation with personal age is analysed through correlation tests. In the next section, the case study environment and the research method regarding this methodology are presented in detail.

2. CASE STUDY AND METHODS

In this paper, the time factor on the structuring of cognitive maps is investigated through the participants' age and spatial analyses of the cognitive maps they have drawn. In this section, the case study environment, the participants and the method are presented.

2.1 CASE STUDY ENVIRONMENT

In regard to the theoretical background, the characteristics of the case study space is determined as a public building experienced recurrently by its participants during a specific period of life. Based upon the autobiographical memory theories, the life period is selected as late adolescence; one of the most recalled periods of life, to obtain the most qualified data. School buildings were accepted as the first potential subject in that case, depending on their repeatedly use by the students on daily bases for three to eight years.

The case study subject is designated as the building of a prominent high school in Istanbul which has been used as an educational facility for the same institution for 83 years. The building was designed by Alexander Vallaury for Ottoman Public Debt Administration and opened in 1896 as the most prestigious building of its age (Figure 1). After the closure of Ottoman Public Debt Administration in 1928, the building was transferred to Istanbul High School (commonly known as Istanbul Male High School) in 1933. The building is located in Eminonu, over a steep site sloped towards the Golden Horn. The plan of the main block is grounded on a rectangle 24 meters to 106 meters which expands to 48 meters to 120 meters with the expansions (Figure 2). It has two basement floors, one ground floor, two middle floors and a roof floor.

The plan schema is shaped around a main hall and a main corridor intersecting at the centre of the building. The classrooms and laboratories line up on the long edges of the main corridor. At the short edges, there are wide classrooms in the form of a half octagon. The four towers at the four corners of the main corridor are used as one or two classrooms in each floor. At the front façade, there is an entrance with a portal and a three floor height wide hall with marble stairs. On the opposite side, there is a main hall and an octagonal tower. Inside the tower, there is a canteen in the ground floor, administrative offices in the first floor and a lounge room in the second floor. There are classrooms, laboratories, wet cores and administrative rooms in the first and second floors. In the first basement floor there are classrooms, a gymnasium, chancing rooms, an atelier and club rooms; and in the second basement there are technical rooms and a closed Byzantium cistern.

Figure 1 - Front view of the school building (Photograph by Tansel Atasagun)

The case study focuses on the ground floor of the building which is one of the two most used floors by students (Figure 2). The floor has 59 defined spatial units including classrooms, laboratories, halls, corridors, canteen, administrative rooms, service spaces and a wet core. The stairs and mezzanine inside the canteen space are also defined as spatial units to present the total syntactic structure of the space and the cognitive maps representing it.

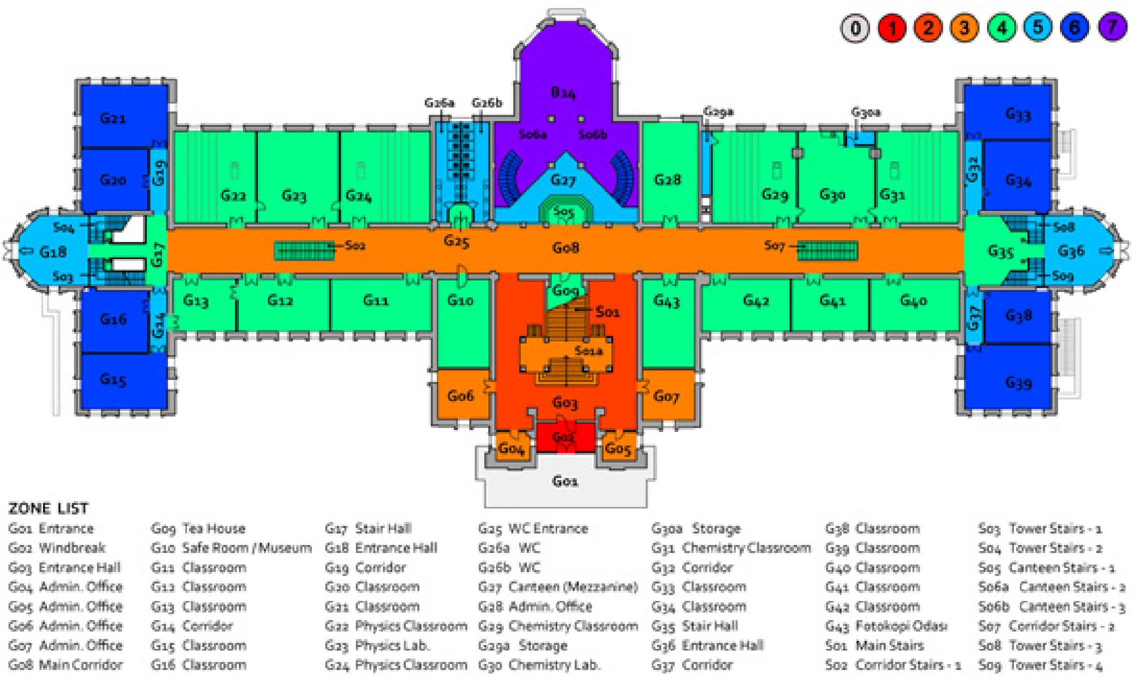

Figure 2 - The convex space schema of the ground floor plan

2.2 PARTICIPANTS

The research group is composed in accordance with Erikson's Theory of Psychosocial Development that defines eight developmental periods in life as infancy (0-2), early childhood (2-4), preschool age (4-5), school age (5-12), adolescence (13-19), early adulthood (20-39), middle adulthood (40-64) and maturity (65+) (Newman and Newman, 2014). In regard to the scope of this paper that focus on the Long Term Memory systems and to avoid the effects of cognitive differences appear between life periods, all of the participants are selected from one period, the adulthood. Additionally, the research group was divided into three age groups in regard to Erikson's sub periods of adulthood to evaluate the outcomes in the grounds of Autobiographical Memory theories.

The research group is composed of 52 adult male participants whom had high school education in the case study environment. The three age groups of the case study are defined as first- early adulthood, second-middle adulthood and third- maturity according to their age range. To rule out recent graduates' advantage on recall, the bottom age value of the first group is specified as the college graduation age (23), the time when an equivalent experience of an educational building has been completed.

Regarding to these constraints; first group includes 15 male participants between the ages of 23 and 39 (average is 32,46), second group includes 30 male participants between the ages of 40 and 64 (average is 53,36) and the third group includes 7 male participants between the ages of 65 and 75 (average is 69,10).

2.3 METHODOLOGY

In order to collect the cognitive data, every participant was asked to draw the plan schema of the ground floor of his school building in two successive sessions that lasts for five minutes. In the first session the participants used black pencil and in the second session they used red pencil. The black and red colours are regarded as indicating the specific differences in drawing periods of each participant and those differences' effect on the number of recalled spatial units.

The data has been generated from two types of analyses of these cognitive maps:

1. Spatial Unit Analysis: This analysis focuses on the contents of spatial units of the cognitive maps. The number of spatial units drawn with black pencil are defined as "Recalled in First Order" (RO1), the number of spatial units drawn with red pencil are defined as "Recalled in Second Order" (RO2) and the sum of these two values is defined as "Total Number of the Recalled Spatial Units" (RT). The RO1 and RO2 values focus on the act of drawing a cognitive map and aim to reveal if the time period of drawing effects the contents of spatial units in a cognitive map.

2. Syntactic Analysis: This analysis focuses on the syntactic relationships between the spatial units drawn in each cognitive map. The structure of cognitive maps mostly represent the topological relations of spatial contexts like a net, independent from the metric or directional properties of that context, such as length or area. On the basis of this structure, the most fundamental spatial relations of the cognitive maps are analysed through justified graphs generated from the convex maps of each cognitive map. Convex maps present the minimum number of convex spaces in a system and a convex space is defined as a space in which any line connecting two points does not cross its perimeter (Klarqvist, 1993). As a rearranged graph of a convex map, Justified Graphs represent every convex space with a node and every connection between two nodes with a line.

At the beginning of the syntactic analysis, (1) the convex map of the ground floor plan was developed to identify the spatial borders of each spatial unit and (2) the root node of the justified graphs was designated as "Zo-Entrance" space (Figure 2). The justified graphs of 52 cognitive maps are generated normatively with regard to these spatial borders and the defined root node (Figure 3).

Three basic syntactic concepts are calculated from these justified graphs; Depth, Mean Depth and Syntactic Step. Depth value represents the sum of the connections that links the root node to all the other nodes in the graph and Mean Depth value is the algebraic function of Depth value from all the other nodes in the graph (Peponis and Wineman, 2002). Both of these values present how much syntactic data is represented in a cognitive map in relation to the number of recalled spatial units. As the third concept, Syntactic Step is regarded as the maximum number of connections that link a node to the root node. This value presents how deep a spatial system is recalled independent from the number of spatial units it comprises.

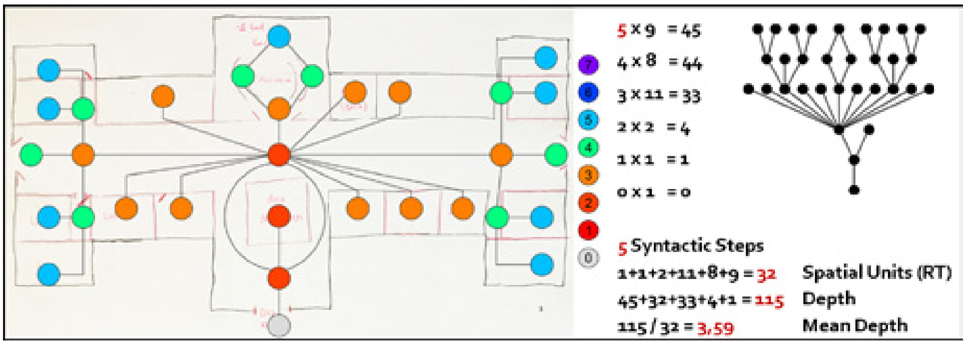

Figure 3 - Syntactic analysis graph of a cognitive map, Participant No:1, Age: 30.

The aim of this case study is searching the time factor on the structure of cognitive maps. In accordance with that, the numerical change in the content of spatial units and syntactic values of cognitive maps are analysed and their relations with the participant age are searched statistically through correlation tests. The outcomes are interpreted according to the age groups representing the life periods of the participants to understand the results in regard to the long term memory theories.

3. RESULTS

All of the 52 male participants had successfully drawn the cognitive map of the ground floor plan. All six values representing the spatial content and the syntactic characteristics of the 52 maps are calculated through spatial unit analysis and a calculation table. The basic descriptive graphics demonstrate that these values tend to decrease as the participant age increases (Figure 4 and Figure 5).

The statistical relationships between these values and the time factor are tested with correlation tests using the IBM SPSS Statistics software.

Firstly, bivariate correlation tests are conducted between the participants' real age and Spatial Unit Analysis values of the cognitive maps to understand the relationship between the age of the participant and how much is recalled from that specific environment independently from the syntactic properties of it.

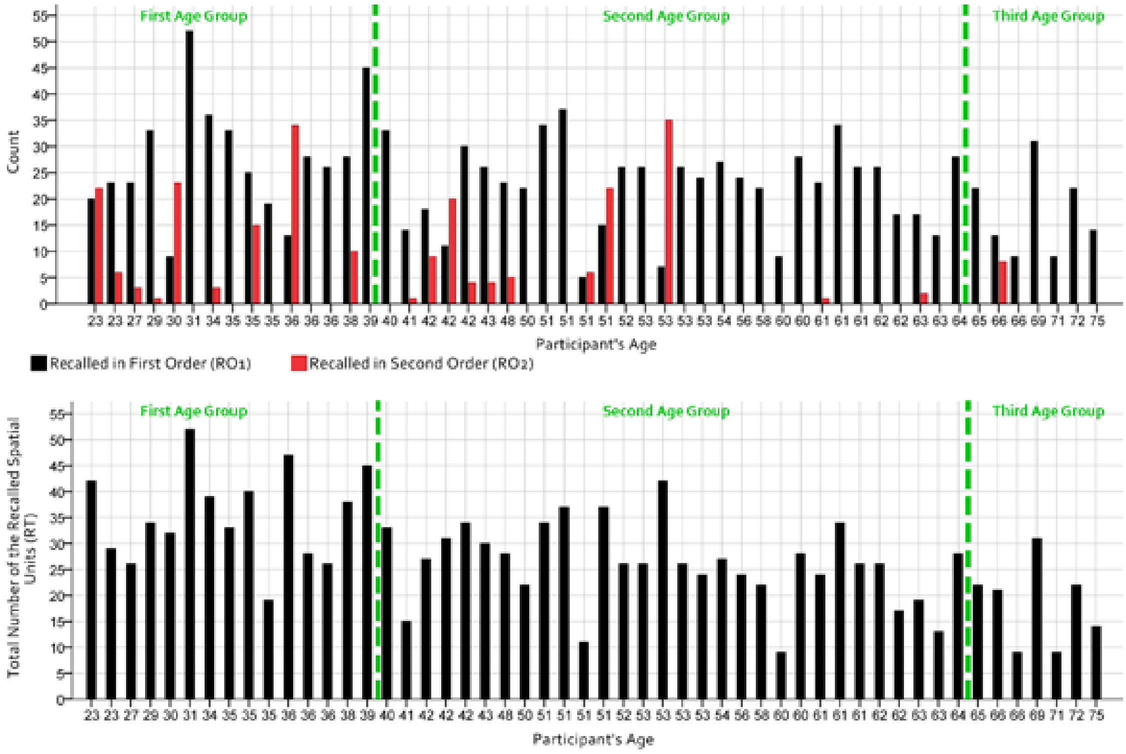

Figure 4 - Graphics representing the changes in RO1, RO2 and RT values according to Participant's Age

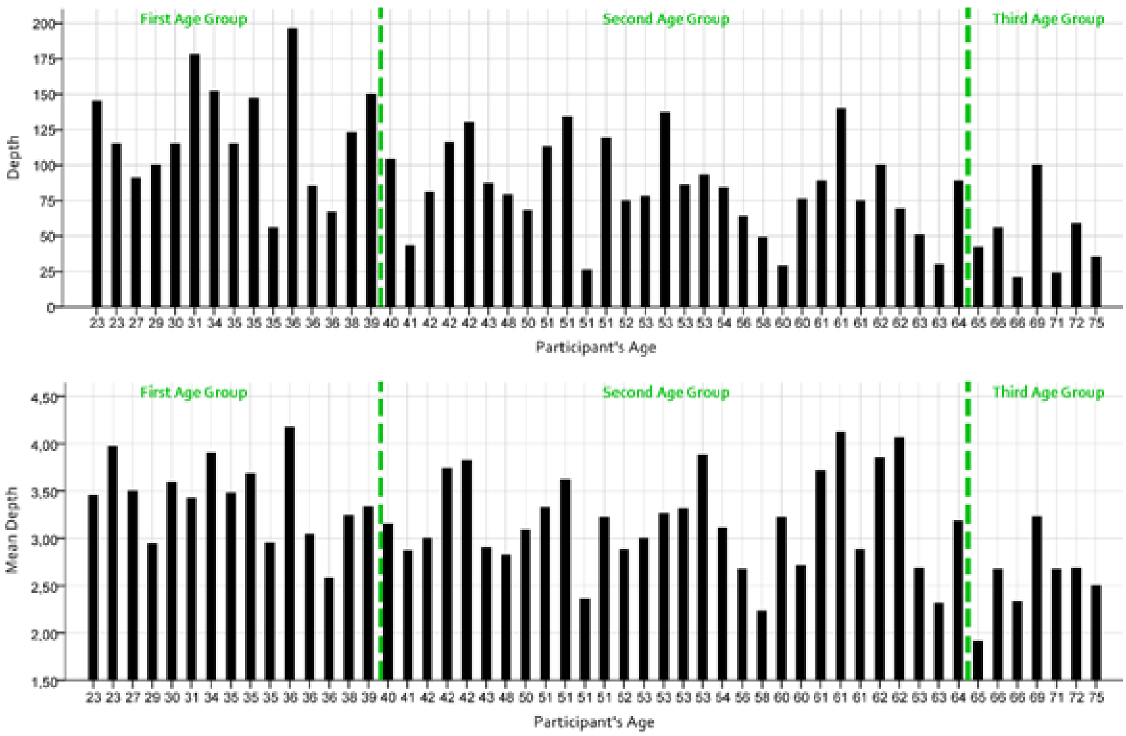

Figure 5 - Graphics representing the changes in Depth and Mean Depth values according to Participant's Age

As shown in Table 1, RO1 value has a low correlation ($r = -0,278$) with the participant's real age in negative direction. Figure 6 shows this correlation as a scattergram in which the number of units Recalled in First Order are not tightly distributed along the line (R2 = 0,077) but still decrease significantly as the age of the participant increases ($p = 0,046$). RO2 value also shows correlation ($r = -0,340$) with the participant's real age in negative direction. This indicates that the number of the spatial units recalled in the second five minutes also decrease as the age of the participant increases and this relationship is significant ($p = 0,014$) in the 0,05 level. The difference in the correlation levels of RO1 and RO2 reveals the difference between participants' time periods of drawing. Nineteen of the thirty participants in the second age group and six of the seven participants in the third age group finished their map in the first five minutes so that these cognitive maps do not offer any RO2 data. The zero values of these participants have changed the correlation level but do not affect the general outcome. The third and last content value RT also shows correlation ($r = -0,574$) with the participant's real age in negative direction. The total number of the recalled spatial units in cognitive maps decrease significantly ($p = 0,000$) as the participants' age increase (Figure 6). This negative correlation approves the first two correlations and shows that the drawing sequence of the spatial units has a weaker relationship with the participant's age than the total spatial information represented in a cognitive map. More importantly, this correlation shows that the amount of spatial information recalled decreases significantly as an adult gets older.

Correlation	**Age – RO1** Recalled in First Order	**Age – RO2** Recalled in Second Order	**Age – RT** Total Number of the Recalled Spatial Units
	$r = -0,278$	$r = -0,340$	$r = -0,574$
	$p = 0,046 < 0,05$	$p = 0,014 < 0,05$	$p = 0,000 < 0,05$

Table 1 - Correlation between Participant's Age and cognitive maps' content values

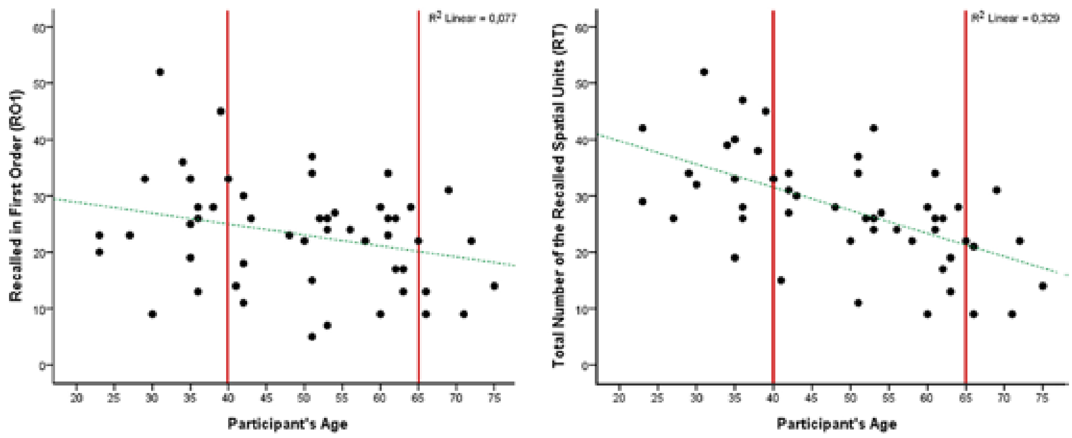

Figure 6 - Scattergram between Recalled in First Order and Participant's Age; Scattergram between Total Number of the Recalled Spatial Units and Participant's Age

Secondly, bivariate correlation tests are conducted between the participants' real age and Syntactic Analysis values to understand the relationship between the age of the participant and the basic syntactic characteristics of his cognitive map representing a specific environment. As shown in Table 2, Depth, Mean Depth and Syntactic Step values of the cognitive maps show higher negative correlation than the RO1, RO2 and RT values of cognitive maps.

The highest correlation is seen for Depth value ($r = -0,577$) in negative direction and it is shown in Figure 7 as a scattergram. This correlation indicates that adding the syntactic step values of every unit as a factor to the total number of the spatial units value slightly strengthens the correlation with participant's real age. The Mean Depth value also shows correlation (r = -0,408) in negative direction with the participant's real age and approves the Depth value's correlation. Addinitonally, the Syntactic Step value itself has a negative correlation (r = -0,421) with the participant's age. This correlation is significant (p = 0,002) at 0.05 level and indicates that syntactic characteristic of a cognitive map has a strong negative relationship with the participant's age independent from the spatial unit count in each syntactic step (Figure 7). In other words, even the number of the recalled units may change, the depth levels of the cognitive maps decrease as the age of the participants increase. This result partly depends on the missing of the deeper spatial units, the units that are farther from the entrance both metrically and topologically (e.g. private wet cores, laboratory storages or classrooms at the corners), from the cognitive maps. This reveals that the deeper spatial units from the entrance mostly got erased from the memory as the participants get older and the shallow spaces successfully continue to keep their places.

Correlation	Age - Depth	Age - Mean Depth	Age – Syntactic Step
	r = -0,577 p = 0,000 < 0,05	r = -0,408 p = 0,003 < 0,05	r = -0,421 p = 0,002 < 0,05

Table 2 - Correlation between Participants' Age and cognitive maps' syntactic values

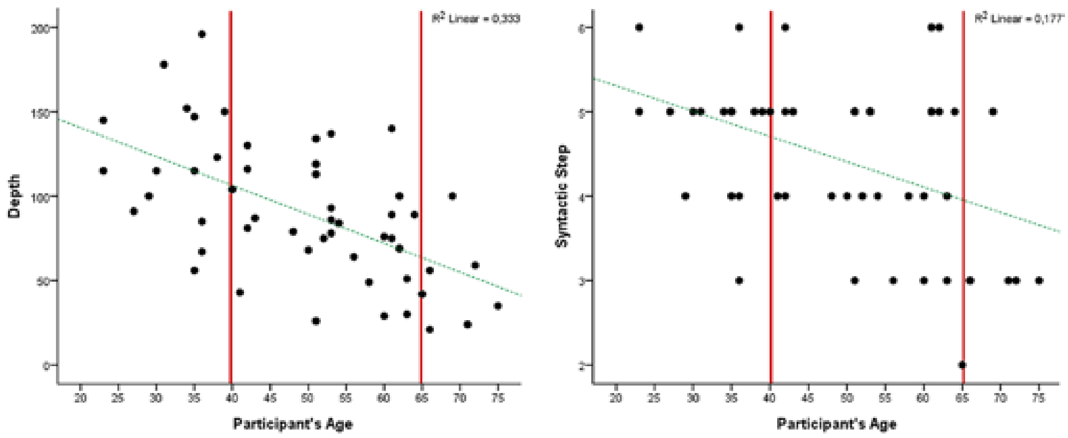

Figure 7: Scattergram between Depth and Participant's Age; Scattergram between Syntactic Step and Participant's Age

All the correlations between the predefined values representing the basic characteristics of a cognitive map and participant's age are significant at the 0.05 level. The number of the participants that draw over five minutes decreases as the age increases and this causes a difference between the contents of spatial units drawn in both orders. Still, the change in the total number of the recalled spatial units has the most significant relationship with the participant's age and indicates that more number of spatial units got erased from memory as the participants grows older as an adult. In addition to that, the correlations between the syntactic values and participant's age are stronger than the spatial unit values' correlations. These indicate that the syntactic structure is an important property of a cognitive map, it is being reconstructed in time and some of this syntactic information is erased from memory as the individual grows older as an adult. Also the deeper spatial units are mostly the ones that got erased from memory as time progresses and as a result of this loss the syntactic system transforms to a shallower one.

It should be noted that the age of the participant here represents two different kinds of the time factor, (1) the current life period that the participant belongs to and (2) the elapsed time over the experience. In this context, the overall of the results show that the spatial content and syntactic qualities of the spatial memory got missing as an individual passes to the following life period and/or that the spatial content and syntactic qualities of the spatial memory got missing as the time progresses after the real experience.

4. CONCLUSIONS

The theoretical background and methodology of this article are based on specific theories that concern about spatial memory and time factor on memory to search the effect of time over the structure of cognitive maps. At the end of the research, case study results approve these theories and indicate that time is a strong factor over the content and the syntactic configuration of a cognitive map.

First of all, the change in the total number of the spaces drawn in cognitive maps shows that how much an individual recalls from a previously experienced space and the period of time the individual uses to represent that memory in drawing decrease significantly as time progresses after the experience. Secondly, the change in the syntactic values shows that the spatial units, mostly the deeper units in a syntactic system are erased from memory in the course of time and the total representation of the spatial syntax of a cognitive map is being transformed to a new and shallower one. These findings present the spatial memory regarding the spatial configuration of a previously experienced space loose some information and transforms to a less deep, less detailed representation of that space as an individual moves forward in life. In plain words, people tend to forget some parts, mostly the deeper parts of a space as they grow older as an adult, but they still store a deformed and reconstructed representation of that space in their memories.

In addition to the main results, this study presents additional data asserting that space syntax analyses are adaptive tools for spatial memory and long term memory researches. In the case study, space syntax analyses offer valuable digital data of cognitive maps which can be statistically evaluated. Regarding to this potential, it is possible to state that further studies could be conducted through syntactic analysis of cognitive maps to search other human or physical factors that may have an effect on the memory. And in conclusion, this article also has the potential to be an inspiring study for the Long Term Memory researches which concern about the spatial concepts like Autobiographical Memory and Episodic Memory.

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