ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY

A DESIGN PROCESS FOR SOCIAL NETWORK DATA-DRIVEN ADAPTIVE ARCHITECTURE

M.Sc. THESIS

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

SOSYAL MEDYA VERİSİ GÜDÜMLÜ ADAPTİF MİMARLIK İÇİN BİR TASARIM SÜRECİ

YÜKSEK LİSANS TEZİ

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Yasin Kutay YÜNCÜLER, a M.Sc. student of ITU Graduate School of Science Engineering and Technology 523161015 successfully defended the thesis entitled "A DESIGN PROCESS FOR SOCIAL NETWORK DATA-DRIVEN ADAPTIVE ARCHITECTURE", which he/she prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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To all creatures that adapt to fluxional circumstances unceasingly,

FOREWORD

First and foremost, special thanks to my family for their patience and endless support during the long research and writing period of this thesis. For sure, completing this study would not be possible without the motivation and encouragement provided by them.

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January 2020

Yasin Kutay YÜNCÜLER
(Architect)

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ABBREVIATIONS

API	**:**Application Programming Interface
DIKW	**:** Data, Information, Knowledge, Wisdom
LBSN	**:** Location-Based Social Network

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SUMMARY

We are living in a rapidly changing world, led by a constantly developing technology. Our daily habits are affected by this progress and newly emerging technologies such as the *World Wide Web* (WWW). Communication, shopping, and information gathering are only a few of these mutated experiences. Such fundamental and continuous changes in daily routines, increase the pressure on architectural spaces to *adapt* to the fluxional circumstances around them. However, Kretzer complains that the implementation of new paradigms to architecture, including the concept of *active spatial adaptation*, is limited due to the conservative essence of the profession. Besides, Kurzweil predicts that the exponentially increasing pace of technological advancements is not going to last. So, the dynamic nature of the current era is not ephemeral. Therefore, it would not be inaccurate to predict that architecture will start to work on new paradigms such as *active spatial adaptation*, sooner or later.

As a consequence of being a centenarian topic, the terminology on the concept of *change* in architecture is significantly crowded and confusing. Thus, before proposing a design process, this research is focused on understanding the concept of *adaptive architecture*. With this motivation, terms related to this concept are explained and discussed from different points of view provided by several architects. Primary terms analyzed by this study are *flexible*, *adaptable*, *responsive*, and *interactive*. The research process of this subchapter consists of a literature review starting from the second half of the 20th century and projects designed and applied after the 1920s. As the author noticed during the research phase, it is neither possible nor necessary to disassociate these terms entirely. Still, this part of the research was able to recognize and report noteworthy distinctions between the mentioned terms such as being *active* or *passive*, being able to *sense* the surroundings or being based on *human intervention*, providing *spatial variability* or not. In light of this process, it would be accurate to state that *adaptive architecture* aims to provide *spatial variability* by *sensing* its surroundings and performing an *active adaptation* accordingly.

As well as comprehending *adaptive architecture*, understanding its elements is necessary before proposing a design process. By refining various frameworks of the concept proposed by different researchers such as Charles Eastman, Holger Schnädelbach, and Gordon Pask, the questions that constitute this concept are cataloged as *"what to adapt," "how to sense,"* and *"how to react."* These three questions are discussed by examining numerous projects designed since the beginning of the 1960s. As revealed under this title, the most common strategies practiced by architects to answer these questions are *adapting to the climatic conditions*, *sensor-based sensing*, and reacting through *hard systems*. Other than discussing these methods by analyzing various projects, this part of the study revealed the essentiality of the *sensing* strategy for the process of *spatial adaptation*. This title also revealed that

even though there are design processes for *sensor-based sensing* and *material-based sensing* in the literature, a design process for *social network data-driven adaptive architecture* is missing. This lack provides the primary motivation for the main purpose of this study.

Following these two steps that intend to develop a proper basement for the research, *a design process for social network data-driven adaptive architecture* is proposed in the third chapter. Even though design processes for *sensor-based sensing* and *material based sensing* are suggested by architects such as Khoo and Leileveld, these schemes do not cover the needs of *social network data-driven* projects. By contrast with the first two *sensing* methods, social network data requires a complex *interpretation* process to become suitable to be employed in an architectural project. This thesis intends to solve this problem by considering the process within the paradigms of *information management*. Accordingly, Ackoff's *data, information, knowledge, wisdom hierarchy* (DIKW) is utilized to constitute a design process. Thus, a design process that consists of three phases as *data*, *stimulus*, and *adaptive space* is developed. Additionally, this scheme contains two processes; *interpretation* and *simulation.* Briefly, the *interpretation* process evaluates the *data* to compute the *stimulus*, and the succeeding process, *simulation*, converts the *stimulus* into the *knowledge* required by the *adaptive space*.

SOSYAL MEDYA VERİSİ GÜDÜMLÜ ADAPTİF MİMARLIK İÇİN BİR TASARIM SÜRECİ

ÖZET

Durmaksızın son derece hızlı olarak değişen bir dünyada yaşıyoruz. İstikrarlı bir şekilde gelişen teknolojinin önderliğinde yaşanan bu değişim günlük hayatlarımızı da derinden etkiliyor. Özellikle de internetin ve *World Wide Web* (WWW)'in bulunması ve yaygınlaşmasının, kısacası *İnternet Çağı*'nın, dramatik etkileri günlük alışkanlıklarımızı köklü bir biçimde değiştirdi. İletişim kurma, alışveriş, bilgi edinme değişen günlük rutinlerimizden yalnızca birkaçı. İnsanlara hizmet etmeye odaklanan bir meslek olduğu göz önüne alındığında, insanlığın bu denli hızlı değiştiği bir dönemde mimarlık ve mimari mekan da bu değişime ayak uydurma baskısı altındadır. Burada kastedilen, mimarlığı günümüzün ihtiyaçlarını dikkate alarak güncellemek değil, mimari mekanın kendisine durmaksızın değişen şartlara *adapte* olma kabiliyeti kazandırmaktır. Keza, yukarıda bahsedilen türden değişimler bir binanın ömründen çok daha kısa sürelerde yaşanmaktadır.

Ancak, Kretzer'in de yakındığı gibi, mimarlık dünyası, mekanın aktif rol aldığı *mekansal adaptasyon* yaklaşımları da dahil olmak üzere, birçok yeni paradigmaya karşı muhafazakar bir tavır sergilemektedir. Öte yandan altını çizmek gerekir ki, Kurzweil'e göre teknolojik gelişmeler üstel artış sergilemektedir. Hal böyleyken, çağımızın dinamik atmosferinin geçici olduğunu düşünmek yanlış olur. Dolayısıyla kabul etmek gerekir ki, mimarlık bu muhafazakar tavrına rağmen er ya da geç bir çok yeni paradigmayla dirsek teması içerisinde çalışmak zorunda kalacaktır. Bu fikirden hareketle söylenebilir ki, çalışmada değinilen *esnek mimarlık* (flexible architecture), *uyarlanabilir mimarlık* (adaptable architecture) ve *dönüştürülebilir mimarlık* (transformable architecture) gibi konseptler halihazırda mimarlık pratiğinde dünya çapında yer bulmuş olsalar da iş burada kalmayacak ve henüz yaygınlaşmamış, mekanın *adaptasyon* sürecinde aktif rol alabilmesini hedefleyen, *tepkimeli mimarlık* (responsive architecture), *interaktif mimarlık* (interaktif mimarlık) ve *adaptif mimarlık* (adaptive architecture) gibi yaklaşımlar da yaygınlaşma şansı bulacaktır.

Bu öngörü neticesinde bu çalışma, bu ve benzer yaklaşımların aralarındaki farklar göz önünde bulundurularak incelenmelerini ve bu sayede, özellikle *adaptif mimarlığın* özgün yanlarının tespit edilmesini, *adaptif mimarlık* konseptinin bileşenlerinin listelenmesini ve bu bileşenleri farklı yaklaşımlarla ele alan tasarımların incelenmesini ve son olarak da, bu iki basamaktan gelen çıktılar eşliğinde, *sosyal medya verisi güdümlü adaptif mimarlık için bir tasarım süreci* önerilmesini hedeflemektedir.

Elbette, mekanın değiştirilebilmesi ya da değişebilmesi fikri *İnternet Çağı* ve beraberinde gelen köklü değişimler neticesinde ortaya çıkmamıştır. Lee'nin de altını çizdiği üzere bu yaklaşım insanlığın tarih öncesine kadar dayanmaktadır. Ancak böylesi geniş bir zamanı ele almak araştırmanın hedefini saptıracağından, bu çalışmada Birinci Dünya Savaşı ile günümüz arasında geçen dönemde ortaya çıkan fikirlere

ve üretilen projelere yer verilmiştir. Birinci Dünya Savaşı'nın mihenk taşı olarak seçilmesinin iki temel sebebi vardır. Birincisi, Estaji'nin de değindiği gibi, bu küresel savaşın mimarlara yerel mimarlığın değişen şartlar karşısında yetersiz kaldığını göstermesidir. Öte yandan, yine bu dönemden başlayarak, mimarlar *fonksiyonalizm* akımının kısıtlı yaklaşımlarına dair ciddi eleştiriler getirmişlerdir. Bu iki süreç neticesinde mimarlıkta değişim konsepti ile ilgili fikirler daha sık tartışılmaya ve uygulanmaya başlamıştır.

Bu yaklaşık yüz yıllık süreç konu hakkındaki fikirlerin gelişmesine zemin hazırlamış olsa da, geçen bu uzun zamanın sonunda terminolojide ciddi bir karışıklık olduğunu görmekteyiz. Bu karışıklığın sebeplerinin terimlerin sıklıkla birbirlerinin yerine geçecek şekilde kullanılması ve kavramların tekrar tekrar tanımlanması olduğu söylenebilir. Benzer bir yanılgıya düşmemek adına, bu çalışmaya *adaptif mimarinin* temel hedefleri belirlenerek başlanmıştır. Bu amaçla, literatür taraması sonucunda bu konseptle ilişkili olduğu tespit edilen *esnek mimarlık*, *uyarlanabilir mimarlık*, *tepkimeli mimarlık* ve *interaktif mimarlık* gibi kavramlar birbirleriyle olan ilişkileri göz önünde bulundurularak incelenmiştir. Bu başlıkta, *adaptif mimari* ile doğrudan ilişkili olmasalar da, bahsedilen diğer terimlerle ilişkili olan bazı diğer konseptlere ve mekansal özelliklere de değinilmiştir.

Bu noktada belirtmek gerekir ki, hem uzun süredir kullanılan bu kavramları birbirinden tamamen ayırmak mümkün değildir, hem de böyle keskin bir ayırdın gerekli olduğu şüphelidir. Yine de, terimlerin farklı mimarlar ve araştırmacılar tarafından ortaya atılan tanımlarına ve bu tanımlar arasındaki farklılıklara ve benzerliklere değinen bu başlık, ele alınan kavramları daha anlaşılır hale getirmeye ve bu terimler arasındaki bazı temel farklılıkları ortaya koymaya çalışmıştır. Bu kapsamda en çok göze çarpan ayırtlar; mekanın *adaptasyonda* aldığı rolün *aktif* olup olmaması, mekanın etrafını *algılama* (sensing) becerisine sahip olup olmaması ve tasarlanan *adaptasyonun mekansal çeşitlilik* sağlayıp sağlamaması olduğu söylenebilir. Bu farklılıklar çerçevesinde *adaptif mimarlığın* etrafını *algılayarak mekansal adaptasyonda aktif* rol almayı ve bu sayede *mekansal çeşitlilik* oluşturabilmeyi hedeflediği söylenebilir. Çalışmanın ilerleyen kısımları da mimarlığın bu alanını bu motivasyonlar çerçevesinde ele alacak şekilde ilerletilmiştir.

Adaptif mimarlığın temel motivasyonlarını anlamak kadar, kavramın bileşenlerini ortaya koymak da bu çalışma için önemli bulunmuştur. Bu nedenle, takip eden başlıkta *adaptif mimarlığı* meydana getiren bileşenler incelenmiştir. Çalışma kapsamında, özellikle *sibernetiğin* mimarlıkla ilişkilendirilmeye başladığı 1960'lı yıllardan günümüze kadar önerilen bazı modeller ele alınmıştır. Çalışma kapsamında incelenen modeller kronolojik sırayla Gordon Pask, Charles Eastman ve Holger Schnädelbach tarafından önerilmişlerdir Bu üç model sentezlenerek *adaptif mimarlığı* oluşturan üç temel soru belirlenmiştir; *neye adapte olunacak*, *nasıl algılanacak* ve *nasıl tepki verilecek*. Bu üç soru aynı zamanda bu başlığın alt başlıklarını da belirlemektedir.

Bu üç temel soru yine 1960'lı yıllardan günümüze kadar üretilen çeşitli yapılar, pavyonlar, enstalasyonlar ve prototipler üzerinden incelenmiştir. Bu araştırma sonucunda ortaya konulmuştur ki; *neye adapte olunacak* sorusuna karşı üretilen yaklaşımlar *iklimsel verilere adapte olmak* ve *insan davranışlarına adapte olmak*, *nasıl algılanacak* sorusunu yanıtlamak için kullanılan stratejiler *sensör tabanlı algılama*, *materyal tabanlı algılama* ve *sosyal algılama* ve *nasıl tepki verilecek* sorusuna karşılık

olarak tercih edilen yöntemler de *mekanik ağırlıklı sistemler* ve *yumuşak robotlardır*. Bu çalışmanın ortaya koyduğu bir diğer durum ise *iklimsel verilere adapte olmak*, *sensör tabanlı algılama* ve *mekanik ağırlıklı sistemler* stratejilerinin diğer yöntemlere nazaran daha çok tercih edildiği olmuştur.

Çalışmanın bu bölümünün değindiği bir diğer önemli husus ise *nasıl algılanacak* sorusunu yanıtlamak için geliştirilen yaklaşımın projenin tüm sistem şeması ve tasarım süreci üzerindeki kuvvetli etkisidir. Keza tercih edilen strateji sistem şemasındaki basamaklanmayı doğrudan etkilemektedir. Örnek vermek gerekirse, *sensör tabanlı algılamada* ek bir işlemleme basamağına ihtiyaç duyulurken, *material tabanlı algılamada* böyle bir basamağa gerek duyulmamaktadır. Çünkü malzeme hem *algılama* hem de *tepki verme* (actuation) adımlarını doğası gereği taşıdığı özellikler sayesinde kendi bünyesinde icra etmektedir. Öte yandan görülmüştür ki, *sosyal algılama* yöntemi kullanılarak tasarlanan projeler bu iki şemaya da uymamaktadır. Literatürde *sensör tabanlı algılama* ve *materyal tabanlı algılama* yöntemleri için geliştirilmiş süreçlere rastlamak mümkündür. Ancak bu çalışma kapsamında yapılan literatür taramasında *sosyal algılama* stratejisi için önerilmiş bir sistem şemasına ya da tasarım sürecine rastlanmamıştır. Bu çalışma bu yöntemi baz alan bir tasarım süreci önererek konuyu kapsamlı bir şekilde tartışmaya açmayı hedeflemektedir.

Çalışmanın ikinci bölümünü oluşturan bu iki başlık vasıtasıyla tezin üçüncü bölümünde sunulacak ve tez başlığına da adını veren *sosyal medya verisi güdümlü adaptif mimarlık için bir tasarım süreci* için sağlam bir temel oluşturmak amaçlanmıştır. Yukarıda da bahsedildiği üzere *sosyal algılama* yöntemi kullanılarak tasarlanan projelerin sistem diyagramları diğer iki *algılama* yönteminin şemalarına uymamaktadır. Bu uyumsuzluğu gidermek için bu çalışma *sosyal algılama* yöntemiyle tasarlanan mimari projeleri bir *bilgi yönetimi* (information management) problemi olarak ele alır. Bu yaklaşımla birlikte hareket edilerek Ackoff'un *DIKW hiyerarşisi* önerilecek tasarım sürecine entegre edilmiştir. Bu hiyerarşisinin ilk üç basamağı diğer iki *algılama* yöntemi için önerilen şemalar ve mimari literatür göz önünde bulundurularak *veri*, *uyaran* (stimulus), *adaptif mekan* olarak değiştirilmiştir. Ackoff'un şemasındaki son basamak olan *bilgelik* (wisdom) ise, mevcut tekniklerle uygulanmasının mümkün olup olmadığına dair tartışmalar devam etmekte olduğundan, bu çalışma kapsamında önerilen tasarım sürecine dahil edilmemiştir.

Burada dikkat çeken en önemli farklılık sosyal medya verisinin *sensör tabanlı algılama* yönteminde *uyaran* ve *aktüasyon* (actuation) basamaklarının arasında yer alan *sisteme* ek olarak, *uyaran* basamağından evvel bir *anlamlandırma* (interpretation) işlemine ihtiyaç duymasıdır. Bu işlem sayesinde *veri* bir *uyarana* ya da *uyaranlar kümesine* dönüştürülebilecek ve sürecin, *sensör tabanlı algılama* tekniğinin şemasıyla büyük ölçüde benzerlikler gösteren, diğer basamaklarına aktarılacaktır. Böyle bir ek işleme ihtiyaç duyulmasının sebebi sosyal medya verisinin mimari kaygılar güdülerek toplanmıyor olmasıdır. Bu işlem sayesinde *uyarana* dönüştürülen *veri*, *simülasyon* basamağı vasıtasıyla *adaptif mekana* aktarılacak ve süreç burada belirlenen zaman aralığına uygun olarak yeniden başlatılmak üzere sonlandırılacaktır.

1. INTRODUCTION

Architectural products such as buildings and public spaces have faced an issue, precisely in the last decades: losing functionality due to changes in user demands, whether abrupt or gradual. Moreover, despite being iconic symbols of the architectural styles that erected them, some buildings ended up with demolishment. This undesirable end appears as a result of inadequacy to meet the changing expectations from users, visitors, residents, or institutions [1]. *Prentice Women's Hospital* (1975) in Chicago by Bertrand Goldberg (Fig.1.1) is one of the most striking instances of this situation. As well as being a representative piece of *brutalism*, this building was a precedent of computational methods in structural design [1, 2]. Still, it was unable to avoid its demise, even receiving support from Chicagoans and famous architects, including five winners of *The Pritzker Architecture Prize* [3].

Stewart Brand describes comparable processes from a broader perspective, by specifying some reasons behind as follows;

> The old factory, the plainest of buildings, keeps being revived: first for a collection of light industries, then for artists' studios, then for offices (with boutiques and a restaurant on the ground floor), and something else is bound to follow. From the first drawings to the final demolition, buildings are shaped and reshaped by changing cultural currents, changing real-estate value, and changing usage. [5]

As well as stating ideas similar to Brand's words, Manuel Kretzer carries the topic further by explaining and emphasizing the effects of our age called the *Internet Era* on architecture. According to him, humanity is experiencing a swiftly and continuously changing world. Therefore, architects and their designs have to suit our time's unique conditions, such as technological progress, population growth, increasing life expectancy, and brand new challenges related to the environment and society [6].

Each of these phenomena cataloged earlier should be analyzed further to comprehend their effects and degree of influence on architecture thoroughly. Still, their weight for this research would be more visible from another perspective. The essential substance revealed by these explanations and unexpected demolitions is how buildings are

Figure 1.1 : *Prentice Women's Hospital* (1975) in Chicago by Bertrand Goldberg (Photographed by Trevor Patt in 2012) [4].

sensitive to the consequences of the changing circumstances. Again, Brand underlines the inevitability of this mentioned process for buildings, even if they are not designed to adapt by their architects, as follows;

> Almost no buildings adapt well. They're designed not to adapt; also budgeted and financed not to, constructed not to, administered not to, maintained not to, regulated and taxed not to, even remodelled not to. But all buildings (except monuments) adapt anyway, however poorly, because the usages in and around them are changing constantly. [5]

In parallel, Holger Schnädelbach states that every building is *adaptable* to some degree on account of the users' initiative [7].

One may conclude from these descriptions that leaving the adaptation process of a building entirely to its users is an option for architects. Nevertheless, the results of such scenarios are far from being satisfactory. Above all, this inadequacy of architectural design delivers friction between user demands and architectural space. Urban history contains many unpleasant examples of such discord. For instance, despite being abandoned by their original owners, *Kowloon Walled City* (1847) in Hong Kong [8, 9] (Fig.1.2) and *Torre David* (1990) in Caracas, the capital of Venezuela [10] (Fig.1.3), survived for decades through continuous modification, however obtrusively by their unforeseen residents. Nevertheless, both started to cause severe public security and

Figure 1.2 : An aerial view of *Kowloon Walled City* (1847-1993) in Hong Kong (Photographed in 1993) [11].

health problems over time. Thus, *Kowloon Walled City* was destroyed in 1993, and despite being a significantly newer building, *Torre David* is currently under the risk of facing the same fate.

When these two famous cases are exposed to the mentioned thoughts and examples, it is required to note that adapting to fluxional circumstances becomes a *sine qua non* for architecture. As the impacts of the *Internet Era* grow and expand, this obligation becomes more visible. Furthermore, Tomasz Jaskiewicz regards *adaptation* as a primal quality that leads an architectural space to become more successful [13]. So, designing this spatial ability elaborately as a part of a building's lifetime comes to the fore as a responsibility of an architect. However, as Kretzer complains too, architecture as a profession is still very conservative and does not tend to evolve to satisfy the requirements of our time [6]. In awareness of this obvious necessity and the mentioned lack of interest, this study aims to examine the concept of *change* in architecture.

Before enhancing the discussion around this aspect, it is necessary to recognize the difference between active and passive design approaches to *spatial adaptation*. Since

Figure 1.3 : *Torre David* (1990) in Caracas, the capital of Venezuela (Photographed by Eneas de Troya, a flickr user, in 2017) [12].

they share the same root word, comparing the terms *adaptable* and *adaptive* would be beneficial to explain this contrast briefly. According to their lexical meaning, *adaptable* represents the capability of being adapted [14], while *adaptive* means *"serving or able to adapt; showing or contributing to adaptation"* [15]. Notably, despite the similarity, *adaptive* as a word differentiates from *adaptable* by carrying a meaning of being active instead of passive. As Schnädelbach describes, the distinction between these two terms used in architecture is similar to the stated lexical difference [7]. From this point of view, *adaptability* as a spatial attribute does not imply an inborn tendency of a structure. It comes into sight only by being forced to change by human-users in accordance with their evolving functional needs. On the contrary, *adaptive architecture* aspires to design spaces that are mainly capable of adapting to users, visitors, inhabitants, and objects through self-action [7]. By being inclined to adapt intrinsically, an *adaptive space* is capable of coming to an agreement with its surroundings.

By taking this skill into account, it is essential to emphasize that active spatial adaptation has a significant potential for handling our perpetually changing world. In parallel, some studies which focus on *flexible* and *adaptable* concepts, such as *Open Building*, revealed that applied examples of these notions had not fulfilled all of their promises [16]. On the other hand, architects have been seeking to develop innovative methods for adaptation in their branch, especially since the 1990s [17]. The *Muscle* projects by Kas Oosterhuis [18, 19], and *Bloom* by Doris Sung [20], and *HygroScope* and *HygroSkin* by Achim Menges [21, 22] are only a few precedents from this period (Fig.1.4). These and comparable projects utilize advanced technologies in several areas such as computation and material science to make a space-driven adaptation possible [23]. Encouraged by the mentioned advantages and applied projects, this research focuses on the design processes for *active spatial adaptation*. In conjunction with this motivation, possible contributions to this research field, which could be provided by other branches, are explained and discussed within the context of this thesis.

Yiannoudes defines *spatial adaptation* as *"the idea that architectural space can flexibly adapt to changing conditions and needs"* [28]. In light of this description, it would be accurate to conclude that sensing the changes that happen in the surroundings is initial to provide an adaptation actively driven by the architectural space itself. Hence, the choice of sensing strategy affects the design process of such projects directly. As far as it is researched during this study, there are three types of sensing in *adaptive architecture*. They are *sensor-based sensing*, *material-based sensing*, and *social sensing*. Compared to *social sensing*, the other two methods are applied more commonly, especially during the last two decades. In parallel with this experience and interest, researchers and architects such as Charlotte Lelieveld [29] and Chin Koi Khoo [30, 31] proposed design processes for *sensor-based sensing* and *material-based sensing*. On the other hand, although its capability to recognize and analyze a wide variety of urban phenomena is revealed by recent research repeatedly [32–40], *social sensing* is utilized in *adaptive architecture* relatively less. With an intention to contribute to the discussion on the potential of this sensing method for *spatial adaptation*, this thesis is aimed to propose *a design process for social network data-driven adaptive architecture*.

Figure 1.4 : From top left to bottom right: the *Muscle Body* (2003) in Centre Pompidou by Kas Oosterhuis and ONL [24], *Bloom* (2011) in M&A Gallery by Doris Sung of DO|SU Studio Architecture [25], *Hygroskin* (2011-2013) by Achim Menges in collaboration with Oliver David Krieg and Steffen Reichert [26], *Hygroscope* (2012) in Centre Pompidou by Achim Menges in collaboration with Steffen Reichert [27].

1.1 Aim of the Study

The prime goal of this research is to propose *a design process for social network data-driven adaptive architecture*. To do so, design processes for different sensing methods, such as *sensor-based sensing* and *material based sensing*, are analyzed. By comparing *social sensing* with these strategies, the originality and specific needs of it are revealed. Followingly, the well-known *data, information, knowledge, wisdom hierarchy* (DIKW) is implemented to the design process to cover these requirements.

As a matter of course, limiting the context to design process suggestions would fall short of sufficiently analyzing the topic. Therefore, three additional objectives are included in the research. In the beginning, this study analyzes various architectural terms that represent different approaches to the concept of *change* and relates to *adaptive architecture*, especially from a relational perspective. Through such analysis, this title intends to prevent confusion on the topic due to the overcrowded terminology. To conclude this part of the study, the fundamentals of *adaptive architecture* are going to be explained. In the following subchapter, the elements and questions which constitute the notion of adaptation in architecture, such as *what to adapt*, *how to sense*, and *how to react*, are examined. By doing so, this part aims to identify and discuss different strategies in the subject by categorizing the research and projects with a wide range of features.

A summary of the aims of this research are listed below;

1. Analyzing the terminology on the concept of change in architecture,
2. Describing the fundamentals of adaptive architecture,
3. Analyzing the elements that constitute adaptive architecture,
4. Proposing a design process for social network data-driven adaptive architecture.

1.2 Methodology

As explained in the previous subchapter, this study concentrates on four particular objectives with distinct focuses under successive titles. Each part needs a different and specific research method that meets its particular requirements. This section aims to propose and explain these methods on an individual basis thoroughly. Still, before illustrating each title's research structure, it is necessary to state the common

features of their progress. First and foremost, all stages of this study rely substantially on *qualitative research methods*. Each phase draws a conclusion through *inductive* processes.

Before focusing on its ultimate goal, this study aims to dispose of confusion caused by the clutter of terminology on the topic. This issue is also highlighted by Nikolaas John Habraken [41] and Joshua David Lee [42]. The research benefits from *relational analysis* to achieve this purpose. As Robinson mentions, this method *"can be used to help explore the full spectrum of possible relationships between analytical themes within qualitative data"* [43]. Along with this statement, he proposes ten distinctive links that are named *key relational forms* as *descriptive*, *comparative*, *semiotic*, *evocative*, *contingency*, *causal*, *reciprocal*, *dialectical*, *conceptual part-whole*, and *contextual part-whole* [43]. Within the scope of this part, the terminology is analyzed to detect any of these ten relations.

On the other hand, a topic of this kind could be analyzed by using *conceptual content analysis* too. However, the primary goal of this title is to reveal the principles of *adaptive architecture* through links among related terms. This intention orientated the researcher to employ *relational analysis* instead of *conceptual content analysis*.

In this section, the mentioned method is applied in three steps. First, the terminology on the concept of *change* in architecture is filtered through a broad literature review to identify the concepts with any of the ten relations mentioned above with *adaptive architecture*. Followingly, the sifted terms, which in this case are *flexible*, *adaptable*, *responsive*, *interactive*, and *adaptive*, are analyzed conceptually and historically. By doing so, these five terms are explained in detail, and the links among them are revealed. As far as they are researched during this study, four different types of relations out of ten are detected. They are *descriptive* (KRF1), *comparative* (KRF2), *reciprocal* (KRF7), and *conceptual part-whole* (KRF9) relations. Through organizing these relations, this stage of the research generates a relation chain from flexible to adaptive. Eventually, in the final step, this title explains the primary purposes of *adaptive architecture* by benefitting from this conceptual ladder.

The next chapter aims to recognize the ingredients of *adaptive architecture*. Different approaches explored by various architects to satisfy the particular needs of these

elements are analyzed under this title. For that purpose, this part of the study refines the literature and examples through the *thematic analysis method*. Braun and Clark define *thematic analysis* as *"a method for systematically identifying, organizing, and offering insight into patterns of meaning (themes) across a data set"* [44]. In addition to this method, this phase benefits from the *similarity-based categorizing and connecting strategies*. As Maxwell and Miller explain, *"similarity-based relations involve resemblances or common features; their identification is based on comparison, which can be independent of time and place"* [45]. This stage intends to prevent a deviation that might be caused by a one by one analysis of selected projects by using these methods. Instead, examples are categorized by their strategy to reveal and discuss their essence.

Similar to the first subchapter, this title is structured as a three-step process too. In the beginning, several approaches to the elements of *adaptive architecture,* by various researchers and architects, are analyzed. These components are then reduced according to their similarities to three design questions; *what to adapt*, *how to sense*, and *how to react*. In the second step, numerous projects with different locations, times, functions, and designers are listed by reviewing the literature widely to constitute a comprehensive project collection. Followingly, these examples are categorized to recognize commonly used strategies to answer these questions under three separate titles constituted by the previous step. Finally, the selected design strategy is explained in the conclusion of each title. The reason for the choice is also explained.

In the third chapter, the research is focused on the prime goal of proposing *a design process for social network data-driven adaptive architecture*. This phase of the study is based on *from theory to new theory* strategy. Briefly, this method utilizes a theoretical approach that is initially developed for a distinct branch and implements it to another attribute to fulfill the needs of a research subject [46]. Considering the primary intention of the research, the necessity of developing a flow from social network data to architectural space becomes visible. From this perspective, this study is employing well-known *data, information, knowledge, wisdom hierarchy* (DIKW) to constitute a suitable design process. The DIKW hierarchy is natively developed for *knowledge management* processes [47], and it is a ladder-like system that explains the

relationships between its steps [48]. Also, this stage benefits from the definition and conceptual framework produced by previous steps of the thesis.

This *exploratory* section of the research consists of three succeeding phases. Firstly, it reviews the DIKW hierarchy conceptually as it is evaluated in *knowledge management*. Subsequently, it analyzes the evolution of this scheme's elements over the decades to understand the terms included in this approach and relations between them comprehensively. At this stage, the *wisdom* concept is excluded from the study to avoid an inevitable digression due to the endless discussions and criticism. By the following step of this title, *data*, *information*, and *knowledge* are implemented to the design process proposed by this study as *data*, *stimulus*, and *materialization*. The particular transactions among these three concepts are named as *interpretation* (from *data* to *stimulus*) and *simulation* (from *stimulus* to *materialization*). After identifying these five phases of the whole process between *social network data* and *space*, these stages are explained under the title in detail.

1.3 Scope of the Study

Apart from the *introduction* and *conclusion*, this research is structured into two sections, the second and third chapters, with distinctive but complementary motivations and purposes. Therefore, the scopes of these parts of the study are explained under this title separately.

Before touching on the primary goal of this research, which is proposing *a design process for social network data-driven adaptive architecture*, this work aims to understand the notion of *adaptive architecture* comprehensively. With this motivation, the first part of the second chapter focuses on the terminology on the concept of *change* in architecture. First of all, the terminology is filtered by being related to *adaptive architecture* in the literature to prevent detour. Through this step, the approaches named *flexible*, *adaptable*, *responsive*, and *interactive* are selected to be analyzed along with the term *adaptive*. Followingly, these concepts are explained and discussed by reviewing the literature and projects which are related to the mentioned terms. Especially definitions of these five concepts and comparisons among them, as proposed by several architects, are covered by this part of the study.

After this discussion on the terminology, the second subchapter intends to catalog the elements of *adaptive architecture* by converting the frameworks suggested by various architects into the fundamental questions of the concept. As defined by this research, they are *what to adapt*, *how to sense*, and *how to react*. The answers given to these questions are explained as subcategories. The precedents from the second half of the 20th century and contemporary examples from the last two decades are analyzed under this title with an intention to discuss the topic adequately. Additionally, the advantages and disadvantages of the mentioned strategies are discussed through this subchapter, as they are explained in the literature by various architects and researchers.

The following chapter consists of a proposal of *a design process for social network data-driven adaptive architecture*. In this section of the thesis, *social sensing* is compared to the other two sensing methods by the computational requirements. In light of this comparison, the design process is considered to be a data flow and correspondingly, to be an *information management* problem. Accordingly, the *data, information, knowledge, wisdom hierarchy* (DIKW) framework is utilized to define the different phases of the information during the process and illustrate the relationships and conversions between them. Ambiguous terms such as *understanding*, *enlightenment*, and *wisdom* are excluded from the study to prevent a digression. These terms are currently being discussed within the context of *information management* [48, 49].

This research implements the three sifted phases that are *data*, *information*, *knowledge*, as *data*, *stimulus*, and *space*. Additionally, the conversions between these three terms are defined as *interpretation* between *data* and *stimulus*, and *simulation* between *stimulus* and *space*. The decisions given by the architect during these subprocesses are also explained within the scope of this title.

2. ADAPTIVE ARCHITECTURE

Humanity is striving in a rapidly changing world [6]. The primary factor that creates this dynamism is the ever-growing technological development. The invention of the *World Wide Web* (WWW) in particular, greatly affected our daily routines. Communication, shopping, and information gathering represent only a few of our mutated habits. As a consequence, society is subjected to a dramatic transformation in unpredicted ways. According to Kurzweil, the rate of advancements in technology is going to keep increasing exponentially [50]. By taking this potentially everlasting progress into account, it would not be inaccurate to claim that the dynamic nature of the current era is not an ephemeron.

Despite being highly conservative, architecture is affected by the fluxional essence of the *Internet Era* in various aspects [6]. Especially after the ubiquitous digital devices had seen the light of day in the 1990s, the idea of implementing notions related to *cybernetics* to architecture became reawakened [28]. Correspondingly, the popularity of the concept of *change* in architecture has increased throughout the last three decades. Numerous experimental installations from this period, such as *Hylozoic Series*, and *Protocell* by Philip Beesley [51–53] (Fig.2.1), the *Muscle* projects by *Hyperbody Research Group* under the baton of Kas Oosterhuis [18, 19], and *HygroScope* and *HygroSkin* by Achim Menges [21,22] (Fig.1.4) aim to perform the *change*. In addition to these works, many researchers revealed various studies on the same topic in a wide range of scales, from materials [54] to building elements [55,56].

These and other comparable works and studies put the potential of *change* as a concept in architecture on stage. Beyond that, they exposed new possibilities for architects in multi-disciplinary collaborations to implement *spatial change* to their designs [59]. For instance, some of the recent research aims to vary and enhance the contribution of professions which are currently working hand in glove with architecture, such as structural engineering [60]. More to the point, other recent projects on this topic pointed out how architecture might cooperate with specializations that are not

Figure 2.1 : From left to right: *Hylozoic Series: Sibyl* (2012) in the 18th Biennale of Sydney by Philip Beesley [57], the *Protocell Mesh* (2012/2013) in the Prototyping Architecture Exhibition by Philip Beesley [58].

conventional for architectural design workflows [61,62]. Chemistry, computer science, electrical engineering, material science, robotics, and software engineering are only a few of these branches [63–65].

The design process, proposed by this thesis, is impressed and guided by the mentioned and comparable recent projects. However, before refining the research by the context of the advancements in *contemporary architecture*, it is necessary to underline that the concepts associated with *change* are considerably older than three decades. In other words, these notions did not come to existence after facing the effects of the *Internet Era* on our daily lives. Even some researchers date the concept of *spatial change* back to the nomadic roots of humanity [66]. As Lee summarizes;

> The goal of accommodating change in architecture is not a new phenomenon. Since prehistoric times humankind has continually reshaped our buildings to suit changing needs. To varying degrees of success, hundreds of examples exist throughout history including non-moderns like the American Plains Indians, Bedouin Nomads, and moderns such as Archigram, the Metabolists, Utopie and many others. [42]

For ages, humanity gained considerable experience in the design and application of kinetic building elements. However, analyzing the whole history of the applications of comparable ideas to architecture would be infeasible in this study. Thus, the research is limited to a time frame from the early 20th century to the present. The purpose behind originating the period at the beginning of the 20th century is its eager atmosphere of discussions of architecture's demand for the notion of *change* [67].

In the 1920s, architects were questioning about designing buildings that are capable of adapting to changing needs and expectations of users [67]. It would be accurate to

Figure 2.2 : From left to right: *Rietveld-Schröder House* (1924) in Utrecht by Gerrit Rietveld (Centraal Museum collection, Utrecht) [73], the *Maison de Verre* (1932) in Paris by Pierre Chareau (Photographed by Subrealistsandu, a Wikimedia user, in 2009) [74].

mention the *First World War* as one of the most extreme events that propel architects through new ideas by showing them the flaws of the *vernacular architecture* against shifting circumstances [66]. Besides, especially starting from the 1920s to 1950s, the arguments on *tight-fit functionalism* had been heating [68, 69]. According to Forty, architects were looking for fresh attitudes with a motivation for *"redeeming functionalism from determinist excess by introducing time, and the unknown"* [70]. As he states, *"against the presumption that all parts of a building should be destined for specific uses, a recognition that not all uses could be foreseen at the moment of design made 'flexibility' a desirable architectural property"* [70]. By adopting this quality, some architects designed and built residential projects that utilize folding and sliding building elements to provide *flexibility* to inhabitants. *Rietveld-Schröder House* (1924) in Utrecht by Gerrit Rietveld [71] and *Maison de Verre* (1932) in Paris by Pierre Chareau [72] are some built examples from this era (Fig.2.2).

Still, establishing an elaborate theory for the idea of *change* in architectural design had to wait until the dawn of the 1960s [75], the exact decade when architecture met *cybernetics* [28]. As mentioned by Gordon Pask, Norbert Wiener defines *cybernetics* as "*the science of control and communication in the animal and the machine*" [76], and it was a newly revealed topic in the 1950s and 1960s. Pask links architecture to *cybernetics* by being a branch based on *system design*. According to him, as a result of this similarity, architecture shares common interests with it, such as *systems thinking* [77]. By the combination of architecture and *cybernetics*, architects introduced a variety of original approaches to the *change* as an architectural concept. Furthermore,

advancing computation technologies triggered discussions by architects on using these notions as a method to reach the *adaptation* [28]. Projects such as the *Fun Palace* (1961–1974) by Cedric Price for Joan Littlewood [28] and relevant publications such as the special issue of *Architectural Design* in September 1969 bring the impact of this keen and rousing period into today's view [75]. Yiannoudes summarizes this era as follows:

> Reyner Banham, Cedric Price, Yona Friedman, Nicholas Negroponte, the members of the Archigram group, as well as the Greek architect Takis Zenetos, were interested in the application of cybernetics in the built environment, as either a conceptual tool or literal technology. They employed cybernetic concepts, like indeterminacy, information feedback, self-regulation and adaptation, in their designs and writings, to envision open-ended user-driven environments. [28]

As a consequence of this period, architectural literature gained numerous terms and conceptual frameworks about this topic over the decades. While most of these approaches are proposed by researchers to broaden the scope of a previous concept, some others came forward depending upon a paradigm shift [42]. One way or the other, as the literature is reproduced in progress after a period, the terminology on the topic became ensnarled. Semantic similarity shared by words used to describe different attitudes towards the architectural notion of *change* is one of the fundamental reasons for this confusion [41]. Terms directly or indirectly related to *adaptive architecture* are described under the first title in this chapter to avoid such complications. By doing so, this part is focused on explaining the main motivations and goals of *adaptive architecture*, as it is referred to in this thesis, through a broad analysis of related terms.

After the clarification of the term *adaptive architecture* through the literature review, its conceptual framework is discussed in the following part of the chapter thoroughly. This title benefits from proposals by different architects and researchers to probe the topic. Holger Schnädelbach's conceptual framework [7], Gordon Pask's cybernetic design paradigm [77], and Charlotte Lelieveld's design processes [29] are only a few of these research. Thus, the elements that compose *spatial adaptation* are addressed. Followingly, distinct approaches to each component of the presented structure are discussed through analyses of several buildings, pavilions, and prototypes. In parallel, the identified strategies are compared to reveal the essential differences between them.

Through these two steps that constitute this part of the study, comprehending *adaptive architecture* and its components in detail is aimed. In so doing, this title is concentrated on providing a sound basis for the following chapter that is aimed at proposing *a design process for social network data-driven adaptive architecture*.

2.1 Understanding Adaptive Architecture through Terminology

Starting from the 1960s, architects have been implementing concepts of different branches such as *computers*, *flexibility*, *impermanence*, *prefabrication*, and *robotics* [75]. In parallel, pioneering architects have proposed a broad spectrum of terms to define their strategies for the idea of *spatial change*. Some were aiming to expand a prior notion contextually, and others to emphasize a paradigm shift. As Lee itemizes, these terms are *adaptable*, *animated*, *collapsible*, *deployable*, *enabling*, *evolutionary*, *flexible*, *intelligent*, *kinetic*, *manipulable*, *mutable*, *open-system*, *portable*, *protean*, *reconfigurable*, *responsive*, *revolving*, *smart*, and *transformable* [42]. Nevertheless, even this long list might be extended. For instance, *polyvalent* was discussed as a concept to provide *change*, especially during the 1960s [68]. Also, notions named *adaptive* and *interactive* aroused the interest of architects, particularly after the appearance of ubiquitous digital devices in the 1990s [28]. Since these terms found a place in the literature, they are also worth a mention in this catalog. Even after this extension, the list of words used to describe the notion of *change* would not be complete.

The congestion of terminology surrounded the paradigm of *change* with a disorienting atmosphere [41]. Therefore, some researchers made a habit of explaining related notions to their concept as an introduction to their research. For instance, Kas Oosterhuis begins his words in his book named *Interactive Architecture #1* by comparing interactive with terms of adaptive and *responsive* [78]. Apparently, the primary purpose of such analysis is to get rid of confusion, caused by the problematic vocabulary of the subject. By doing so, researchers intend to clarify the concept on which they aim to focus. With the same impulse, this title aims at comprehending the concept of *adaptive architecture* through an extensive analysis of terms that show any of ten *key relational forms* (KRFs) defined by Robinson [43].

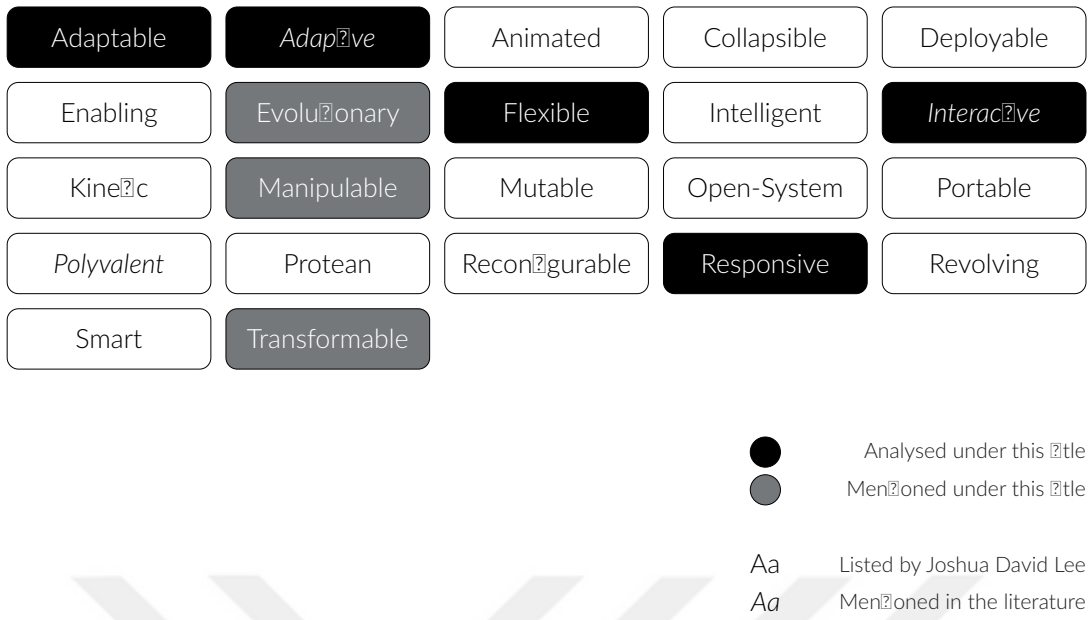

Figure 2.3 : Terminology on the concept of *change* in architecture.

Each term that describes an approach to *change* as a notion in architectural design is associated with *adaptive architecture* to some degree. However, the initial goal of this research is not to explain the whole terminology on the topic but to propose a design process for adaptive public spaces. In parallel, the primary objectives of this title are describing the motivations behind the *adaptive architecture* and stating promises that are given or not given by this concept. Therefore, to avoid digression from core purposes, this title is limited to the design notions frequently linked to the term *adaptive* by the literature. As far as it is researched within the scope of this study, the concepts which meet this criterion are *adaptable*, *flexible*, *interactive*, and *responsive* (Fig.2.3).

However, analyzing only these four terms together with *adaptive* would be neither sufficient to understand the notion in depth nor more than a replica of the current literature. To prevent such undesirable deficiency, some other concepts such as *evolutionary*, *manipulative*, and *transformable* and spatial attributes such as *variability* and *sensing*, which are paired with the mentioned five terms by earlier research, are also mentioned under this title. As going to be explained in the parts of this subchapter in detail, four of ten KRFs are found among these five primary concepts, additional concepts, and spatial qualities. They are *descriptive* (KRF1), *comparative* (KRF2), *reciprocal* (KRF7), and *conceptual part-whole* (KRF9) relations.

This subchapter examines these concepts mostly through definitions and comparisons that exist in the literature. Besides, the discussion on these terms benefits from lexical and conceptual meanings, as well as morphology when necessary. Through these analyses, this part of the study aspires to reveal the similarities and differences among these terms, more than drawing them on an individual basis. Before proceeding with these five terms, it is essential to note that the discussion is not seeking the best strategy to reach the concept of *change* in architecture, but understanding the notion of *adaptive architecture* by interpreting the terminology.

2.1.1 From Flexible to Adaptable

Starting from the 1920s, the concept of *change* in architecture has been arousing the interest of numerous architects [67]. The reason behind this has changed substantially over time. Several milestones in the history of humanity and architecture affected this process directly. During the first half of the 20th Century, two design concerns were more apparent as motives for implementing *change* as a feature to the buildings. First, *World War I* compelled architects to realize the incapabilities of *vernacular architecture* in case of an alteration in conditions [66]. During similar decades, many architects questioned the *tight-fit functionalism* [68,69] and searched for alternatives to its restrictive essence [70]. As an outcome of the discussions around these two topics, several approaches to the *spatial change* were introduced by pioneering architects in these decades.

Flexible is one of the earliest terms used in architectural literature to describe the idea of *change*, together with words such as *convertible*, *collapsible*, and *adaptable* [42]. The first modernist example of this notion, *Rietveld-Schröder House* in Utrecht, the Netherlands by Gerrit Rietveld, was built in 1924 [70]. This pioneering design was followed by several projects such as *Maison de Verre* (1932) in Paris by Pierre Chareau [72] and *Maison du Peuple de Clichy* (1939) in Paris by Beaudouin, Lods, Bodiansky, and Prouve [70]. Also, long before Western examples, Japanese architecture was using a variety of plan types and building elements that could be categorized as *flexible* [79, 80].

However, the primary reason behind starting with this notion is not the chronological order, but the word's frequent occurrence in the descriptions of other terms and studies.

Most recent research on the architectural notion of *change* uses *flexible* as an element or feature of their study. For instance, the term exists in the literature either as an architectural material attribute [81] or a design strategy to reach another *change* concept [82].

This phenomenon has a history dating back from the 1950s to the 1970s. Avant-garde architects and artists such as Yona Friedman from France, Constant Nieuwenhuys (better known as Constant) from the Netherlands, and Cedric Price from Britain proposed various ideas and buildings that carry out *flexibility* within the structure, however, promise for much more [70]. The *Fun Palace* (1964), not completed but gave inspiration to many others, and *Inter-Action Centre* (1972-1977) in Kentish Town, North London, both by Cedric Price, are two well-known examples from this period [70, 83]. Because of this concentricity of the term *flexible* with other concepts of *change*, comprehending this notion first is essential to discuss others thoroughly.

The scope of *flexibility* in architecture is extended in the course of a century. As a consequence of this expansion, a discrepancy in this concept became noticeable in recent studies. For instance, Till and Schneider defined *flexible housing* in 2005 as *"housing that can adapt to changing needs of users"* [84]. Through this definition, one may infer that this concept implies both active and passive structures capable of functioning every imaginable strategy to deliver *spatial adaptation*. Besides, in the same decade, some other researchers describe *flexible buildings* as passive systems that lean on external intervention [59].

To prevent such contradiction, this part of the research benefits from earlier definitions and examples. Yona Friedman defines the term flexible as *"transformable at will by the individual"* [67]. Even though this description seems restricted and narrow, its accuracy becomes more visible by analyzing the state of the notion at the beginning of the 19th Century. The precedents of this approach were instrumenting sliding or folding walls, floors, and roofs [70]. In this respect, the strategies of *flexibility* display similarities to characteristics of *transformable objects* that can be *foldable*, *retractable*, or *shape-shifting* as Hoberman lists [85]. It is possible to find different studies that identify some iconic buildings which benefit from *flexibility* such as *Schröder House*

and *Maison de Verre* as *transformable*[1], instead of *flexible* [42]. From this perspective, it would not be inaccurate to deduce that *flexible* as a notion was mostly referring to *physical transformation*.

In the late 1960s, the notion of *flexible architecture* reached significant popularity [66]. Nikolaas John Habraken's concept, named *Open Building*, made a remarkable contribution to this reputation [67]. *Open Building*[2] is an approach to *flexibility* in housing architecture, and it is based on separating the *infill* from the *support*. By this segregation, the concept intends to free the *infill* [66, 67]. Habraken was impressed by Le Corbusier's Domino House[3] (1914) while developing this innovative notion [41]. The idea applied in different countries and by this means it has matured over the decades [87]. The *Molenvliet* housing project (1974) in Papendrecht, the Netherlands by Frans van der Werf and the *NEXT21* project (1994) in Osaka by Yoshitaka Uchida, which is directly inspired by Van der Werf's residential design, are two breakthroughs of the concept's progress [41, 86].

Independently of its worldwide reputation, the *Open Building* principle is a milestone in the evolution of *flexibility* as a spatial quality for another reason [66]. By courtesy of its bilateral essence, the approach linked this notion to the term *adaptable*. Insomuch that, these words are mostly used together as a couple throughout the decades [88]. For instance, Robert Kronenburg categorizes *Beaubourg Cultural Centre*, and *Sendai Mediatheque* as *flexible*, *adaptable*, and *culturally responsive* at the same time [89].

Habraken's formula contributed to enhancements in the vision for discussions on both of these terms. Nevertheless, this linkage caused disorientation with the meaning of these two ideas due to their overlapping definitions [41]. Besides, *adaptable* and *flexible* as terms have a significantly longer history than other terms analyzed within the

[1] *Transformable* as a term is mentioned in this study only through its similarity to *flexible architecture*. Still, it is necessary to note that *transformable architecture* is a concept that is independent of the term *flexible*. Lee describes this approach by analyzing both definitions by several researchers and the lexical meaning of the word. According to his definition, *transformable architecture* is *"buildings and structures that are able to rapidly take on new shapes, forms, functions, or character in a controlled manner through changes in structure, skin and/or internal surfaces connected by articulated joints"* [42].

[2] As Schmidt III and Austin report, the concept had been named as *Support/Infill* (SI) from the 1960s to 1984. In that year, the term morphed into the *Open Building Simulation Model* (OBOM). Ultimately, it is mentioned as the *Open Building* today [86].

[3] *Maison Domino* is categorized as *flexible* by Schmidt III and Austin. On the other hand, the same authors also mention this design as a precedent of a strategy named *Open Plan* to reach *adaptability* in architecture [86].

context of this study. As a consequence, contradictions and discrepancies outcropped throughout their history. Thus, it has become difficult but necessary to distinguish these terms from each other, at least from a contextual perspective.

As far as it is researched in this thesis, there are two essential differences between the notions of *flexible* and *adaptable*. First of all, *adaptable* as an idea differs from *flexible* by relation to time. According to Leaman and Bordass, *adaptability* aims at long-term and extensive changes, while *flexibility* targets short-term transformations [90]. In parallel, Beisi also emphasizes the long-term purpose of *adaptability* [91].

These two terms also contextually differ from each other. For instance, Steven Groak individualizes the concepts of *adaptable* and *flexible* explicitly. As he explains, the term *adaptable* refers to *"capable of changing use,"* while *flexible* means *"capable of changing position"* [92]. In 1974, Rabeneck also highlighted the capability of *adaptable architecture* to allow changes in function [79]. As Joshua David Lee quotes in his research, Richard Medlin describes this difference in the same year parallelly as follows;

> Flexibility suggests the potential of a designed entity to accommodate a variety of different functions or conditions external to the designed system (i.e. open plan school is conceived with adequate flexibility to enable accommodation of a wide variety of academic processes); whereas Variability is more the potential to reorganize or change a designed entity in response to different functions or external conditions (i.e. building envelope that admits solar energy in the winter and is capable of being altered to reflect solar energy in the summer is variable). Adaptability is the general term that encompasses both flexibility and variability and can be thought of as the potential of a designed entity to passively accommodate or actively respond to different functions or external conditions. [42]

In parallel, Fox mentions *adaptable space* by being able to fit distinct uses through various adjustments [93]. In addition to these explanations, Negroponte compares *flexible architecture* with the term *manipulative* from a similar point of view. In his view, *flexible space* is capable of meeting the requirements of only a few different functions. On the other hand, *manipulative*, as a concept, promises to fit various activities through a wide range of alterations [94]. In parallel, Lelieveld notes that the variety of possibilities provided by *flexibility* is limited [59].

Despite these distinctions, it is almost impossible to disassociate one of these concepts from the other. Because the functional alteration and the physical change generally operate together [66]. By taking this collaboration into account, the differences

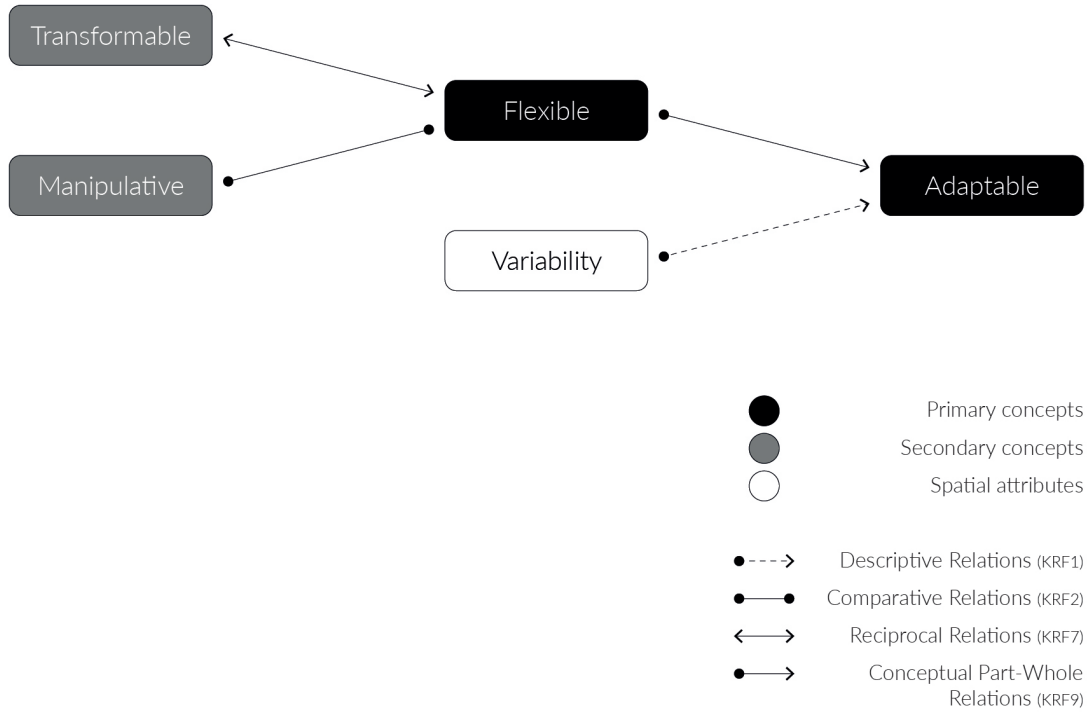

Figure 2.4 : Relations among the concepts and spatial attributes mentioned under this title.

between these terms are not evaluated as discrepancies in this study. As stated by Medlin in the paragraph mentioned above, it would be more reasonable and fair to conclude that *adaptability* is the whole of *flexibility* and *variability*, rather than an entirely different notion from *flexible* (Fig.2.4).

Also, it is fundamental to mention the definitions of the term *adaptable*. One of the pioneering explanations of this concept was propounded by the Ministry of Housing and Local Government of the United Kingdom in 1961 comprehensively. The ministry defines *the adaptable house* as *"the house which could easily be altered as circumstances changed - is a recurring theme in the evidence we received and in our own thoughts"* [95]. Decades later, Lee describes this concept by combining different explanations proposed by several architects with the word's lexical meaning. According to him, *adaptable architecture* means *"buildings that are planned to be easily altered or modified to fit changing functions or external conditions, before or after occupancy"* [42]. In parallel, Ross defines *adaptability* as *"the ease with which buildings can be physically modified, deconstructed, refurbished, reconfigured, repurposed and/or expanded"* [96]. As it is coherent to infer from, most of these definitions emphasize a change in pursuance of the functional needs and external

conditions. More importantly, all of them share an opinion about *adaptability*, and indirectly about the concept named *flexible*, that both refer to a *passive* strategy indeed.

On the other hand, several definitions of the concept *adaptable* that cover both active and passive methods to perform *spatial adaptation* appear in the literature. As a consequence of this equivocality, confusion about the term *adaptable* with the concept of *adaptive* occurs. This situation will be discussed under the following title.

2.1.2 From Responsive to Adaptive

During the first half of the 1900s, the concept of *change* in architecture centered around the deficiencies of *vernacular architecture* [66] and criticism on *tight-fit functionalism* [68, 69]. For several decades, these discussions, which cover both theory and practice, served architecture as the flagships of the idea of *change*. On the other hand, both of these topics were summoned by architects' very own, within existing paradigms of architecture. From this point of view, it can be inferred that architects had perceived the notion of *change* from a narrow perspective, that is limited to their discipline, back then. As a consequence, approaches proposed during this period for the first time, such as *flexible* [59] and *adaptable* [7], are highly contingent upon human intervention.

However, this fundamental limit was going to be exceeded in the second half of the 20th century. Especially starting from the early 1960s, architecture has diversified from its usual concerns to unfamiliar paradigms of a new research field, *cybernetics* [75].[4] Several architects such as Yona Friedman, Cedric Price, and Nicholas Negroponte started to seek opportunities to implement the concepts related to *cybernetic*s, such as *indeterminacy*, *information feedback*, *self-regulation*, and *adaptation*, to architecture [28]. Thanks to these research and discussions, the idea of designing spaces that have their own purposes and intentions came to the fore [94]. Even though the technology at that time was insufficient to apply these ideas [98], the original concepts proposed during those years were a breakthrough for the idea of *spatial change* in architecture.

[4]Before its effects on architecture, *cybernetics* influenced other branches of the art. Nicholas Schöffer was one of the pioneers of implementing this newly emerging field to sculpture. Gregor Muir categorizes his artworks in three classes; *Spatiodynamish* (1948), *Luminodynamism* (1957), and *Chronodynamism* (1959). In Particular, 52-meter-high *Cybernetic Tower of Liege* and *Microtime Sculptures* are only two of his art pieces. These artworks were utilizing electronics such as colored projectors, microphones, photoelectric cells, and programmed electric motors [97]. His works are found to be significant for architecture by the author for revealing the potential of *cybernetics* to create *dynamic spaces*.

Concepts named r*esponsive*, *adaptive*, and *interactive* sprang in those years by virtue of the vibrant discussions [99]. The research on these concepts is settled on a new field *"between embedded computation and physical dynamism"* [65].

Responsive is the earliest architectural term used to define the *active spatial change*. The term was presented by Negroponte in the late 1960s and gained significant popularity during the 1970s [100, 101]. According to him, the concept *responsive* is *"the environment is taking an active role, initiating to a greater or lesser degree changes as a result and function of complex or simple computations"* [94]. Decades later, Sterk explains the common usage of this concept in parallel as *"a type of architecture that has the ability to alter its form in response to changing conditions.* [102]. In his recent research, Lee intends to propose a comprehensive definition by integrating the descriptions proposed by various architects with the one offered by the Oxford Dictionary. According to him, *responsive architecture* is *"any element or social process of the built environment that quickly answers to a stimulus (either social or environmental) during the design, construction, and/or maintenance phases of a project"* [42].

Despite showing slight differences, actively operating the *spatial adaptation* in reaction to *external stimuli* is common in these three definitions of *responsive architecture*. Still, it is necessary to note that the focal point of these three approaches varies. For instance, Negroponte emphasizes the role of computation, Sterk highlights being able to form-change, and Lee points to a quick response.[5]

As well as the chronological order, the essentiality of the *response* in self-reacting spaces is also a fundamental reason behind starting this title with *responsive architecture*. For instance, Marco Pesenti regards the term *responsive* as an ability of *adaptive building skins* together with being *multifunctional*and *dynamic* [103]. Similarly, John Frazer specifies being *responsive* as a prerequisite for *evolutionary architecture* [104]. Even Negroponte, the father of the term [100], uses *response* as an

[5]In addition to mentioning the term's relation to time, Lee's definition of *responsive architecture* is inclusive of all types of *responsiveness* as they are categorized by Negroponte in 1974 [42]. According to Negroponte, there are three subcategories of responsiveness. As he catalogs, *"There's a responsive design technology that people are talking about; participation, advocacy planning. There is a responsive building technology. And the third is a responsive architecture itself"* [42]. This part of the study is primarily focused on the third category of *responsiveness*. Still, mentioning Lee's description found noteworthy by its comprehensive essence.

architectural quality that can be performed by *active spaces* even though they are not categorized as *responsive* by him [94]. So, comprehending the differences between this concept and other terms related to the *spatial change* is essential to explain the principal features of other *active* terms too.

With its increasing popularity in the 1970s, various relations of *responsive architecture* to other terms also started to take place in the literature. In 1975, Negroponte stated that the term *responsive* is used interchangeably with concepts named *adaptable* and *reactive* [94]. Beyond this, Richard Medlin employs *responsive* as an adjective to describe a type of *adaptable architecture*[6]. According to him, *responsive adaptability "recognizes design as a continuous process and includes mechanisms to receive feedback on design performance and to feed forward an adaptive response"* [42]. Despite limiting the term *responsive* to an adjective of *adaptable architecture* only, Medlin's definition emphasizes the distinction between this term and *adaptable* by pointing to what is added to *adaptability* by *responsiveness*. As explained in the previous title, *adaptable architecture* provides *passive spatial change* and depends on *human intervention*. On the other hand, the adjective *responsive* broadens this essence with the ability to receive *feedback* from the environment and utilizing this information to perform a *response*.

In addition to this significant contrast between *responsive* and *adaptable*, Fox underlines the essentiality of input provided by sensors for a *responsive control system* [93]. Still, it is necessary to note that being able to *sense* the environment alone is not sufficient to deliver complete *responsiveness*. Doris Sung also notes this inadequacy while explaining *responsive behavior* from the perspective of a different branch, *robotics*. As she states;

> Once the robot receives sensory input, it must be able to respond by doing or changing something. The connection between input (sensing something) and output (acting on it) differentiates the robot from just being a sensor. [65]

In parallel, Mark Meagher emphasizes the essence delivered by the *automation*. Although he categorizes both buildings as *responsive*, Meagher compares *Maison de Verre* (1932) in Paris by Pierre Chareau and *Institut du Monde Arabe* (1988) in Paris by Jean Nouvel by the characteristics of their *responsiveness*. *Maison de Verre*,

[6] As Lee quotes, Medlin discusses *adaptable architecture* under four categories as *contextural*, *external*, *internal*, and *responsive* [42].

categorized as *flexible* under the previous title, depends on a *change* that is operated by users. On the other hand, *Institut du Monde Arabe* performs the distinguishing feature of *responsive architecture* through its automated and motorized mechanism [105]. Negroponte focuses on a similar distinction and compares the concept *responsive* with terms *flexible* and *manipulable*. According to him, both *flexible* and *manipulable* are based on *human intervention*. On the other hand, *responsive architecture* intends to design environments that are capable of *"taking an active role"* in *spatial adaptation* [94].

Besides, Wolf Hilbertz describes the relationship between the terms *responsive* and *flexible* from another perspective. According to him, *responsive architecture* is the combination of advanced industrialization and a high level of *flexibility* of use. As can be noticed, Hilbertz commentates *flexibility* as an attribute of a *responsive environment*. In addition to defining the term's relation to *flexibility* and technology, he emphasizes the necessity of *cybernetic technologies* for *responsive architecture* [106].

As well as the *responsive architecture*, the term *adaptive* also faces uncertainty due to the equivocal definitions of *adaptable*. By contrast with the definitions mentioned in the previous title, some architects describe the term *adaptable* as if it covers not only passive but also active approaches to *spatial adaptation*. For instance, while explaining the change provided by *adaptable architecture*, Lelieveld states that it *"could be executed by the building system itself, transformed manually or could be any other ability to transform by an external force"* [59]. In parallel, Schmidt expresses the interest of this notion as *"the capacity to adjust or be adjusted to suit new situations"* [86]. Beyond this, while cataloging descriptions of *adaptable architecture* in the literature, Estaji includes the definitions of *adaptive architecture*, like it is not a separate concept [66]. These and comparable ambiguous descriptions and interchangeable usages may give rise to the thought that *adaptable* includes both *active* and *passive* spatial attributes. Therefore, they cause confusion with the distinction between the terms *adaptable* and *adaptive*.

Interestingly, despite defining the *change* performed by an *adaptable space* as it includes both *active* and *passive* methods, Leieveld describes the terms *adaptable* and *adaptive* distinctly in two different research published by her. According to her, *adaptable architecture* refers to *"an architecture from which specific components can*

be changed in response to external stimuli, for example the users or environment" [59]. On the other hand, she describes *adaptive architecture* as *"architecture of which specific building components can adapt in response to changing parameters, such as user preferences, environmental aspects or mechanical changes"* [29]. Although both of these sentences share a similar structure and emphasis, they signify that *adaptive spaces* are active while *adaptable spaces* are not.

Even if this distinction is proposed consciously or not, it indicates a point that is underlined by many other architects too. One of the most comprehensive explanations about the difference between these two terms is proposed by Schnädelbach. According to him, *"All Architecture is adaptable on some level, as buildings can always be adapted 'manually' in some way"* [7]. On the other hand, *"Adaptive Architecture is concerned with buildings that are specifically designed to adapt (to their environment, to their inhabitants, to objects within them) whether this is automatically or through human intervention. This can occur on multiple levels and frequently involves digital technology (sensors, actuators, controllers, communication technologies)"* [7]. As might be concluded from his statements, *adaptive architecture* is based on the inbred feature of being able to adapt.

In addition to their confusing usage with *adaptable*, a similar situation can be seen between the terms *adaptive* and *responsive* in the literature. Unfortunately, benefitting from the literature review is not suitable to distinguish the distinctions between the terms *responsive* and *adaptive*. The reason behind this incompetence is these two terms' common usage to replace each other like a synonym, even in the same research paper. However, even in these studies, it is possible to notice various slight differences between them. For instance, Lignarolo benefits from both of these notions to explain the shape-morphing façade system designed by him and his team. However, in this paper, *adaptive* is used to characterize words related to building systems and elements. On the other hand, the term *responsive* is used together with the stimulus; in the case of the mentioned project, it is wind [107]. It is possible to see this difference in other studies too [108]. Even though the difference between the roots of these adjectives may lead us to recognize a slight distinction between them, *adaption* is often used in the literature while describing the term *responsive*. For instance, Meagher

defines *responsive architecture* as *"any building or building component designed for adaptation to change in its surroundings."* [105]

As well as specifying the scope of a concept, indicating the characteristics which are not involved by it is indispensable. When it comes to the case of the terms named *adaptive* and *responsive*, understanding their distinction with *interactive* is beneficial to set the framework for its definition. In the literature on the concept of *change* in architecture, these two terms are commonly used together with *interactive*. Beyond this interpenetration of these three words, Lucy Bullivant incorporates the verb *interact* into the definition of the term *responsive*. According to her, *responsive environments* are *"spaces that interact with the people who use them, pass through them or by them"* [109].

By contrast with the mentioned complementary use and over-inclusive definitions, Kas Oosterhuis specifies the distinction of the term *interactive* from *adaptive* and *responsive* strictly. As this pioneer of *interactive architecture* states;

> What is Interactive Architecture? Let me first clarify what it is NOT. Interactive Architecture - from here on abbreviated as iA - is NOT simply architecture that is responsive or adaptive to changing circumstances. On the contrary, iA is based on the concept of bi-directional communication, which requires two active parties. Naturally, communication between two people is interactive; they both listen [input], think [process] and talk [output]. [78]

In parallel, Kretzer states the interests of *interactive architecture* as *"interaction elaborates on concepts concerning interaction and adaptation that exceed pure control and automation mechanisms but attempt to change, learn, and evolve dynamically"* [99]. Although Oosterhuis' explanation is criticized by some architects, especially the ones who work on *responsive architecture*, [42] it specifies the distinction between these terms explicitly. Thereby, it is found valuable for this research. In compliance with his elucidate description, it is necessary to emphasize the exclusion of *bi-directional dialogue* between space and the human from the definition of *adaptive architecture*.

As far as it is researched during the thesis, two distinct clusters that rose to the surface as a result of interchangeable usages of different words are recognized. The first of them consists of the term *adaptable*, *responsive*, and *adaptive*. The second group of concepts includes *responsive*, *adaptive*, *interactive*. Even though it is possible to sift them from the concepts of *adaptable* and *interactive*, a marked difference between

adaptive and *responsive* is not recognizable in the literature. Still, nuances between these two can be noticed by analyzing the usage of these terms. In light of the research proposed under this comprehensive subchapter, this title represents the primary goals of *adaptive architecture* to provide *spatial variability* by *sensing* its surroundings and performing an *active adaptation*.

2.2 Elements of Adaptive Architecture

Especially since the 1960s, the idea of spatial adaptation has been arousing the interest of architects increasingly and, in parallel, discussed more comprehensively. Frazer summarizes this decade as *"architectural thinking in the sixties was preoccupied with issues of flexibility, impermanence, prefabrication, computers, robotics, and a global approach to energy, resources and culture"* [75]. *Cybernetics*, a newly appealing research field back then [76], started to attract architects' attention in the same decade because of having common interests and sharing a similar philosophy [77]. During the following decades, architects had been discussing concepts related to *cybernetics* and *active spatial change* such as *adaptation*, *indeterminacy*, *information feedback*, *and self-regulation* [28].

Applications of these ideas could not become prevalent due to the technological insufficiencies [98]. But still, various concepts related to the *active spatial adaptation* are proposed and discussed during these decades [99]. These approaches by numerous architects laid the foundations of the concept of *change* in architecture. Yiannoudes the significance of this period as;

"Although their projects were mostly unrealized experiments, similar ideas re-emerged in the 1990s, when the ubiquity of digital devices brought forth, once again, the possibility to synthesize architecture with computer systems, in order to make spaces adaptable to changing needs." [28]

In parallel with Yiannoudes, Lelieveld also emphasizes the importance of complex computation processes for an intelligent *adaptation* in architecture [59]. Thanks to the advancements in *computer science*, accessibility of the programming interfaces have been increasing during the last two decades. In parallel, the notable progress of realizing these and comparable ideas began in the 1990s, when technological devices became more ubiquitous [28, 55]. Hence, architects became able to advance their

approaches to the concept of *active spatial change* [110]. Beyond being possible, prototyping such approaches are becoming increasingly feasible since then [82, 98].

However, computer systems would not be sufficient without the advancements in *material science*. In his book titled *Information Materials*, Manuel Kretzer underlines the potential of newly developed materials for architecture in detail. He also represents some advanced techniques under five groups as *kinetic movement*, *light emittance*, *color change, electricity*, and *structural performance* [111]. These categories may be considered as spatial scenarios too, which architects can utilize in the service of their branch. Also, this catalog can be extended. In addition, Sung emphasizes the importance of the advancements in *robotics* [65].

The opportunities which are delivered by the technological developments in a variety of research fields did not come alone, but together with new and idiosyncratic subjects. Therefore, architects and researchers proposed several conceptual frameworks and sets of characteristics. Pask took one of the earliest initiatives in the year of 1969. According to him, an *adaptive environment* consists of five stages as below in the given order;

1. *"Specification of the purpose or goal of the system"*,
2. *"Choice of the basic environmental materials"*,
3. *"Selection of invariants which are to be programmed into the system"*,
4. *"Specification of what the environment will learn about and how it will adapt"*,
5. *"Choice of a plan for adaptation and development"* [77].

As Negroponte cites, Charles Eastman lists the ingredients of *adaptivity* in architecture from a similar perspective as *"a sensing device, a control algorithm, a change mechanism, and a control setting."* [94] After more than three decades, Holger Schnädelbach proposed a conceptual framework of the same genre of architecture in his recent paper. He explains the practice-related part of his framework as *"what adaptive buildings react to, what elements in adaptive architecture are adapted, the method for adaptation and what effect adaptations have"* [7].

When it is taken into account that the primary goal of this study is suggesting a viable and rational *design process for social network data-driven adaptive architecture*, the gravity of elements and questions that constitute the *adaptive architecture* will be more precise. Hence, this research shares a similar motivation to the studies given above. Accordingly, the principles and characteristics which are illustrated by the previous research are combined under three main questions as *"adapt to what," "how to sense,"* and *"how to react."*

With an intention to comprehend the effects of the developments in *structural engineering*, *mechanical engineering*, *material science*, and *computer science* on this specific field of architecture, numerous applied projects, pavilions, and prototypes are analyzed under these three titles through subcategories[7]. By this means, this title collects the strategies which are developed to overcome the mentioned questions and intends to address them before proposing the design process. By doing so, this subchapter is aimed at discussing the different approaches, rather than explaining the projects one by one. Comparisons between these distinct strategies are also included in these titles. To represent the topic more inclusively, this part of the research examines not only *adaptive* examples but also *responsive* and *interactive* ones.

2.2.1 Adapt to What?

Yiannoudes defines the term *adaptation* in architecture as *"the idea that architectural space can flexibly adapt to changing conditions and needs"* [28]. Considering this description, it would not be inaccurate to conclude that the *external stimuli* are the initial points of *adaptive spaces*. In respect to this priority, the answer given to the question highlighted by the title is the determinant of an architectural space's adaptability skill. Thanks to the advancing technology [6], our predictive capacity kept increasing beginning from the 1960s, when Gordon Pask foresaw the positive impact of *cybernetics* on this research area [77]. So today, architects have the opportunity to give various answers to the mentioned question. Youssef Osama Elkhayat categorizes these approaches as *"interaction with light"* and *"interaction with human."* [112] In parallel, in this part of the research, these strategies will be reviewed under two categories.

[7] It is essential to note that the primary focus of this part of the study is not discussing every single work related to this topic, but understanding distinct methods utilized by architects to develop active spatial adaptation. Therefore, only a selection of projects representing different strategies to the mentioned three questions is analyzed under this title.

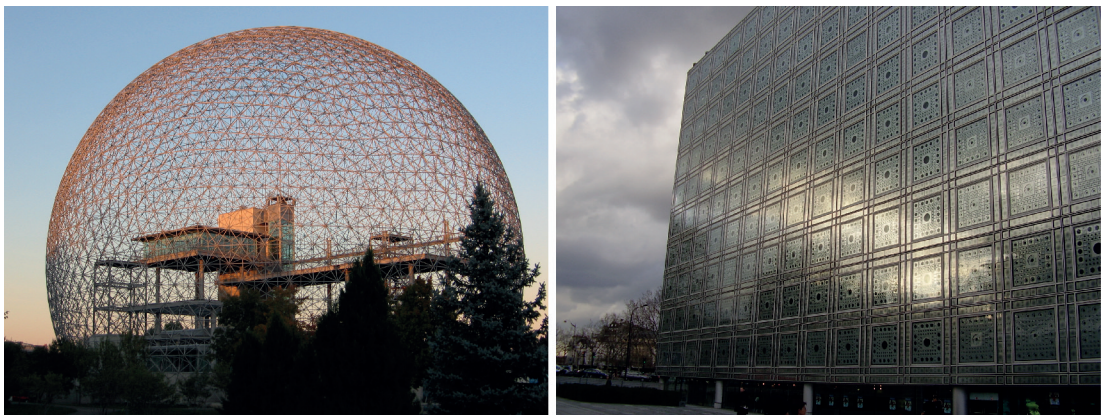

Figure 2.5 : From left to right: The *Montreal Biosphere* (1967) in Montreal by Richard Buckminster Fuller (Photographed by Emmanuel Milou in 2005) [117], *Institut du Monde Arabe* (1989) in Paris by Jean Nouvel (Photographed by axxlpower, a flickr user, in 2006) [118].

These groups are defined as *adapting to the climatic conditions* and *adapting to the behavior of people*.

Among these two kinds, utilizing climatic data is relatively more popular as an approach to *architectural adaptation*. As recent research presented in detail, this technique has a remarkable potential to fulfill the sustainability agenda's specific needs [113, 114]. It would be reasonable to underline this promise as the prime basis of this strategy's relatively broader application. For instance, since the precedents of adaptive façades such as *Los Angeles Hall of Records* (1962) in Los Angeles by Richard Neutra [115], the *Montreal Biosphere* (1967) in Montreal by Richard Buckminster Fuller[8] [99], and *Institut du Monde Arabe* (1989) in Paris by Jean Nouvel [105], architects have been pursuing the adaptation to daylight (Fig.2.5). Buildings of the last decade, such as the *Q1 Headquarters* building for ThyssenKrupp (2011) in Essen, and *Al-Bahr Towers* (2012) in Abu Dhabi, prove that this purpose is still extant [114] (Fig.2.6). All of these projects are benefiting from a similar scheme. Their façades transform in accordance with the sun angle during the daytime to reduce energy consumption through different strategies such as controlling the interior illumination, regulating the solar heat gain, and reducing heating or cooling requirements [116].

Compared to these constructed designs, *Gardens by the Bay* (2012) in Singapore by Wilkinson Eyre Architects also reacts to climatic conditions through its responsive

[8] *Montreal Biosphere* (1967) was initially designed as the *United States Pavilion* at the *Montreal Expo* in 1967. In this pavilion, Buckminster Fuller's identical concept of the geodesic dome with a responsive façade, previously presented in *Garden of Eden* (1955), has taken a step forward [63].

Figure 2.6 : From left to right: The *Q1 Headquarters* building for ThyssenKrupp (2011) in Essen by JSWD Architekten [119], *Al-Bahr Towers* (2012) in Abu Dhabi by AHR [120].

façade [114] (Fig.2.7). However, as distinct from the examples mentioned above, the system that manages the façade of this building is not based on a single type of data but detects alterations in multiple variables that affect the interior air condition. Instead of tracking the sun's position alone, the control system in this example simultaneously measures three different values; humidity, light levels, and temperature [116]. Similar to this example, the façade of the *Media-TIC* building by Enric Ruiz-Geli of Cloud 9 responds to changes in various parameters such as temperature, humidity, and air pressure [112, 116]. This fundamental distinction is going to be addressed under the next title in further detail.

Apart from these applied projects that are mostly oriented to lowering energy consumption caused by heating and cooling, some recent projects aim to achieve relatively more experimental targets. One of these objects is implementing the advancements in material science to architecture. *Bloom* (2011) in Los Angeles by Doris Sung of DO|SU Studio Architecture [20] and *Hygroskin* (2013) by Achim Menges are two well-known examples of this motivation [114] (Fig.2.8). These pavilions were designed to utilize active materials such as *thermobimetal* and *hygroscopic wood*, which are intrinsically able to sense and react to a specific climatic condition. For instance, *Hygroskin*'s wooden panels respond to humidity changes, while *Bloom*'s bimetal skin bends and straightens as the heat increases and decreases [20].

Quite the opposite, there are a few projects that do not focus on the progress of material technology, but the utilization of simple components to provide an aesthetic effect only.

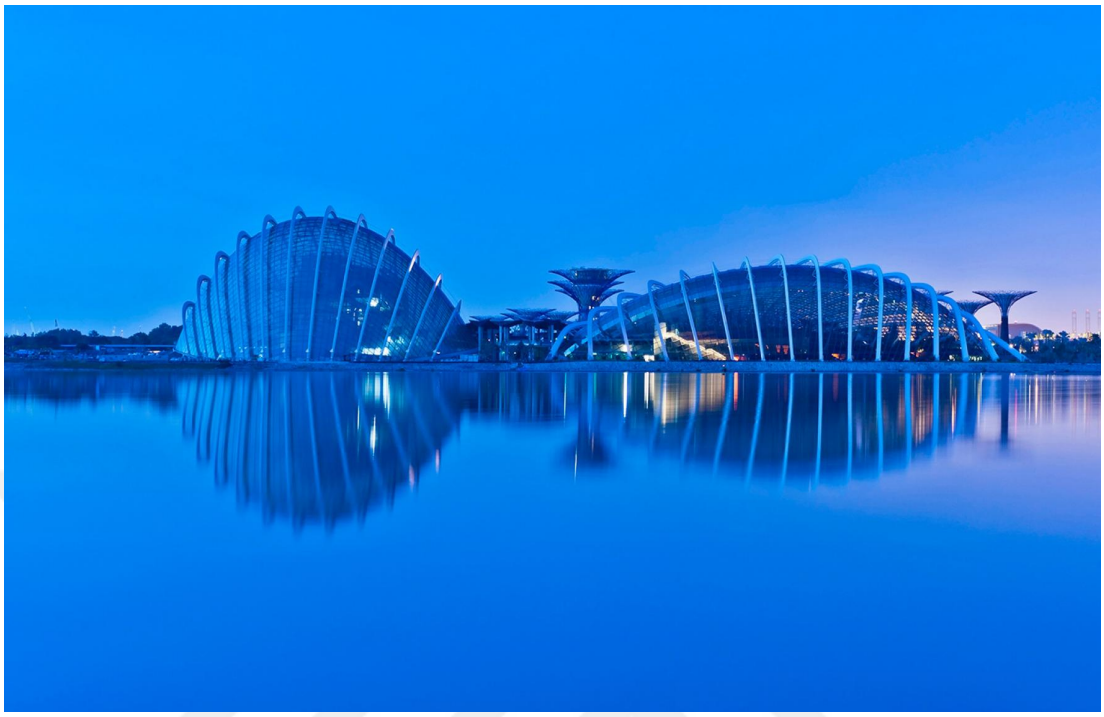

Figure 2.7 : *Gardens by the Bay* (2012) in Singapore by Wilkinson Eyre Architects [121].

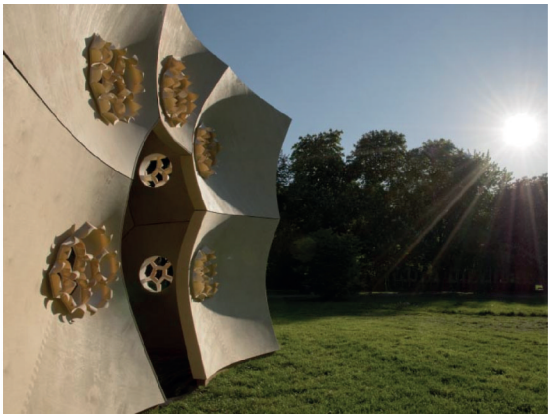

Figure 2.8 : From left to right: *Bloom* (2011) in M&A Gallery by Doris Sung of DO|SU Studio Architecture [25], *Hygroskin* (2011-2013) by Achim Menges in collaboration with Oliver David Krieg and Steffen Reichert [26].

Articulated Cloud by Ned Kahn is a notable example of this kind. *Articulated Cloud* is a sunscreen designed as a building skin for *Children's Museum of Pittsburgh* (2011) in Pennsylvania. As Kolarevic notes, this façade *"consists of tens of thousands of hinged resin flaps that flutter in the wind"* [116]. Although categorizing the action performed by this façade as *spatial adaptation* would be inaccurate within the context of the literature, still, this example is noteworthy by showing the range of complexity in architectural applications of such ideas.

Even though they are rare compared to the climatic data-driven designs, numerous pavilions that process human-related data to adapt to their surroundings are also practiced, especially over the last two decades. In particular, interactive projects depend on this type of data in connection with their essence, which is based on bidirectional dialogue [78]. *Aegis Hyposurface* by Mark Goulthorpe of dECOi Architect(e)s is one of the earliest examples of this approach (Fig.2.9). The first working prototype of this project was completed in 2001 [122]. Although it was not proposing a strategy for implementing comparable systems to architecture, *Hyposurface* was a remarkable and encouraging installation with its complex mechanism. In brief, it is a façade-like surface and consists of metal plates that respond to a variety of external triggers, mostly sound, by being actuated by pneumatic pistons [100].

Another design followed the footsteps of this precedent in the next year. In 2002, *Topotransegrity* by 5Subzero was featured in the *Latent Utopias* exhibition curated by Zaha Hadid and Patrick Schumacher [123] (Fig.2.9). As well as utilizing the data related to human behavior, this prototype was similar to *Hyposurface* by employing a pneumatic system. Still, it is essential to note that this project differs from Goulthorpe's work by its scale. Rather than proposing a building element only, *Topotransegrity* is original by being aimed at performing an adaptive public space by processing real-time feedback from its surroundings [124,125]. The project benefits from pressure-sensitive materials to feed its *"non-linear developing surface"* [126] with the data on the pedestrian routes [127].

On the other hand, Holger Schnädelbach considered the topic from a different aspect. He brought an original goal for architecture forward, shaping the user's psychology to provide therapy [130]. According to him, a space that benefits from the data on

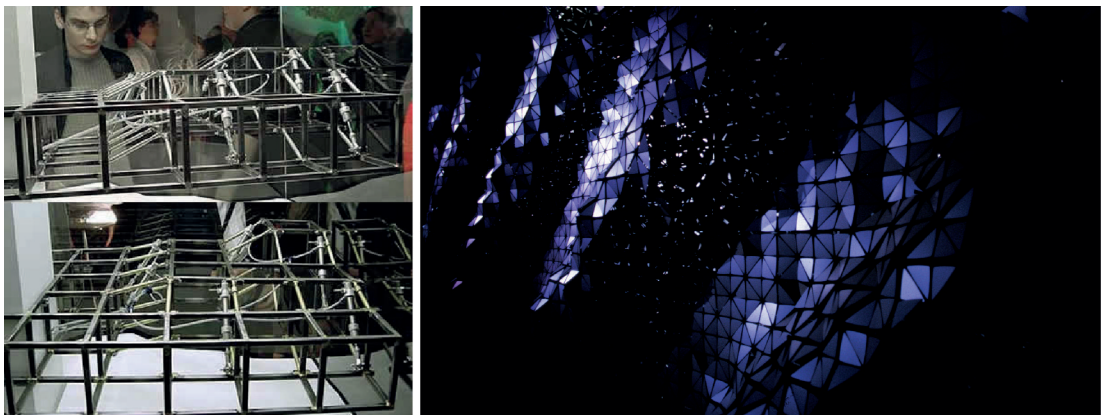

Figure 2.9 : From left to right: *Aegis Hyposurface* (2001) by Mark Goulthorpe of dECOi Architect(e)s [128], *Topotransegrity* (2002) in the Latent Utopias exhibition by 5Subzero [129].

the visitor's biology *"can indeed trigger behavioural and physiological adaptations without giving people instructions"* [110]. His prototypes, named *ExoBuilding* (2012), are aimed at adapting to physiological data, which comprises the measurements of a single inhabitant's heartbeat and respiration. The developed prototype was combining the digitally computed data with embedded LEDs, and servo motors operated structure. By doing so, it was becoming capable of visually representing her or his heartbeat and changing its size in harmony with its occupant's breaths [131].

Particularly during the 2010s, the strategies utilized in the mentioned examples are practiced from different perspectives by architects in numerous pavilions and installations. *Dune 4.2* (2010) in Rotterdam by Daan Roosegaarde of Studio Roosegaarde [112, 132], and *Phototropia* (2012), *Resinance* (2013), and *Resinance 2.0* (2013) by Manuel Kretzer, his team, and supporters [6, 99, 133] are only a several of them (Fig.2.10). The mentioned projects are focused on a wide variety of external stimuli. For instance, *Dune 4.2* responds to the passing people's sounds and movements [134], while *Phototropia*, *Resinance*, and *Resinance 2.0* react to touch, and user presence [6, 99, 133].

Other than these examples based on direct interactions that occur in their immediate environment, also the projects that employ innovative digital tools to obtain crowd-sourced data are noteworthy for being mentioned under this category. *D-Tower* (1998-2004) in Doetinchem, the Netherlands by NOX is one of the precedents of this approach (Fig.2.11). The sculpture was focused on representing the mood of the urbanites by changing its color. For that purpose, the project had been utilizing data

Figure 2.10 : From top left to bottom right: *Dune 4.2* (2010) in Rotterdam by Daan Roosegaarde of Studio Roosegaarde [134], *Phototropia* (2012) by a student team supervised by Manuel Kretzer [135], *Resinance* (2013) by a student team supervised by Manuel Kretzer, Benjamin Dillenburger, and Hironori Yoshida [136], *Resinance 2.0* (2013) at the 2013 ACADIA conference by a team supervised by Manuel Kretzer [137].

Figure 2.11 : From left to right: *D-Tower* (1998-2004) in Doetinchem, the Netherlands by NOX [140], *Open Burble* (2006) in Singapore by Usman Haque (Photographed by Eng Kiat Tan in 2006) [141].

obtained through a specially designed website to make an extensive questionnaire to the urbanites [138]. Similar to *D-Tower*, *Sky Ear* (2004), a one-night installation by Usman Haque, was also seeking an opportunity to interact with crowded people. As Cantrell explains, *"Sky Ear is a cloud of glowing balloons and cell phones, suspended in the sky to sense and visually display the present and relative electromagnetic phenomena of ubiquitous cellphone networks"* [132]. Visitors to the project were asked to call or send text messages to the cloud to trigger the system by manipulating the electromagnetic field [132]. Two years later, Haque took this approach a step further in his more recent project named *Open Burble* (2006) in Singapore by benefitting from relatively more advanced mobile technologies [139] (Fig.2.11).

As mobile devices become ubiquitous, social networks evolve into a daily habit for people. As well as the researchers in other fields, architects are also interested in taking advantage of this advancement to obtain the data related to the crowds, especially starting from the 2010s. *Datagrove* (2012) by Future Cities Lab at ZERO 1 *Seeking Silicon Valley 2012* Biennial and the *Minneapolis Interactive Macro-Mood Installation* (MIMMI) (2013) by Invivia and Urbain DRC are only two social network data-driven examples from this period (Fig.2.12). These projects differ from each other by their structure and strategy of interaction. For instance, *Datagrove* was an armature-like installation that reacts to the collected data through LEDs, LCDs, and speakers. Besides, *MIMMI* was *"an iconic inflatable cloud"* [132] that responds to the analyzed information through light displays and a misting-based cooling system. Still, both

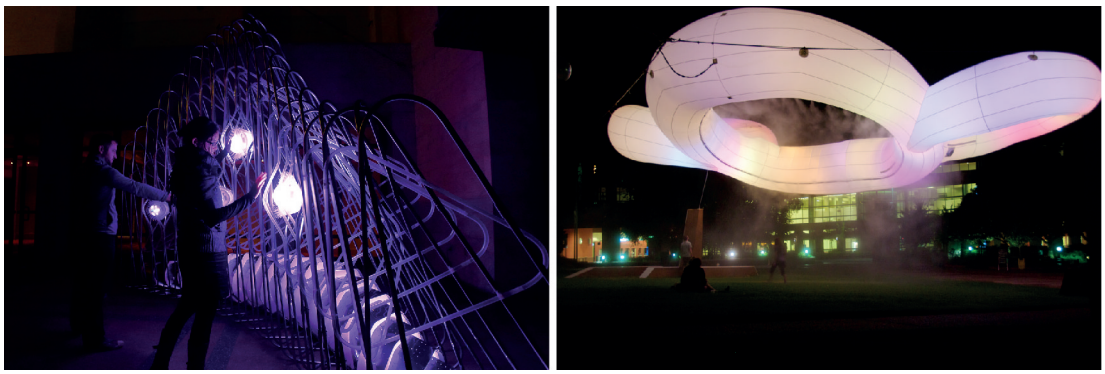

Figure 2.12 : From left to right: the *Datagrove* (2012) by Future Cities Lab at ZERO 1 Seeking Silicon Valley 2012 Biennial [142], *MIMMI* (2013) in Minneapolis by Invivia and Urbain DRC [143].

pavilions were similar by performing with the data gathered through the APIs of the popular social network services such as Twitter [132].

Although most of them are not applied to building-scale cases, at least not yet, the approaches utilized by the precedents mentioned above are remarkable by revealing the potential of the concepts named *adaptive*, *interactive*, and *responsive* in architecture. Besides, it would be accurate to infer from the variousness of these strategies that the question titled *"what to adapt"* is highly based on the designers' goals and preferences. Thus, it is neither possible nor beneficial to compare these distinctive answers given to this question within the interests of this research. Still, it is necessary to emphasize that a significant number of urbanites are involved in public areas [82]. Therefore, the substantiality of human-related data for public spaces becomes more visible. In accordance with this gravity, the design process proposed in the following chapter is based on the data collected from the people, primarily through social network services. Also, through operating a less common approach, the author intends to enhance the originality of the study.

2.2.2 How to Sense?

Negroponte explains his vision on spatial adaptation as *"a physical environment that knew me could be more active"* [94]. As he complains too, this idea was not generally accepted between architects in those days [144]. This explanation implies a relationship between the space and its surroundings that can be possible only by implementing *sensing* skills to architecture. However, for decades, these and similar concepts had not been widely applicable. Thanks to technological developments,

today, it is possible and feasible to utilize several *sensing* methods in the artificial environment [82, 101]. Under this title, the approaches to this essential part of *active spatial adaptation* will be analyzed under three categories. They are *sensor-based sensing*, *material-based sensing*, and *social sensing*. Their fundamental capabilities, essential differences, and effects on choosing the *actuation* method will be discussed in this part of the study by explaining these strategies through applied projects. Additionally, their processes will be analyzed through diagrams based on schemes for active and passive systems proposed by Lelieveld. According to her, active systems consist of *external stimulus*, *system*, and *actuation*. Besides, passive practices do not contain a *system*, but *external stimulus* and *actuation* [29].

Especially after the 1990s, sensors became ubiquitous as well as other technological components [28, 62]. Three decades later, today, we are currently living in a world that is surrounded by several types of these small devices [105, 131]. By definition, a sensor is *"a device that detects or responds to a physical or chemical stimulus (e.g., motion, heat, or chemical concentration)"* [145]. With the capability to detect and record external changes, sensors provide the connection between the adaptive system and its surroundings [114]. There are a wide variety of sensor types with the ability to sense different stimuli such as heat, humidity, light, motion, sound, touch, and proximity [145]. Because of this broad range of variety and accessibility, sensors are widely used by both the researchers and the construction industry to obtain the required data for spatial adaptation.

Most of the early applications of dynamic building elements were benefiting from sensors in varying technological degrees. For instance, the *Los Angeles Hall of Records* (1962) in Los Angeles by Richard Neutra traces the sun with a mechanical eye on the rooftop [115] (Fig.2.13). In the same decade, automated retractable screens of *Montreal Biosphere* (1967) in Montreal by Richard Buckminster Fuller are triggered by light sensors [63] (Fig.2.13). Similarly, *Institut du Monde Arabe* (1988) in Paris by Jean Nouvel utilizes hundreds of light sensors [105] (Fig.2.13). Although implementing sensors to track a light source or measure the luminance could not find a wide application area for decades, this approach's successors became widespread in the construction industry during the 2010s. The *Q1 Headquarters* building for

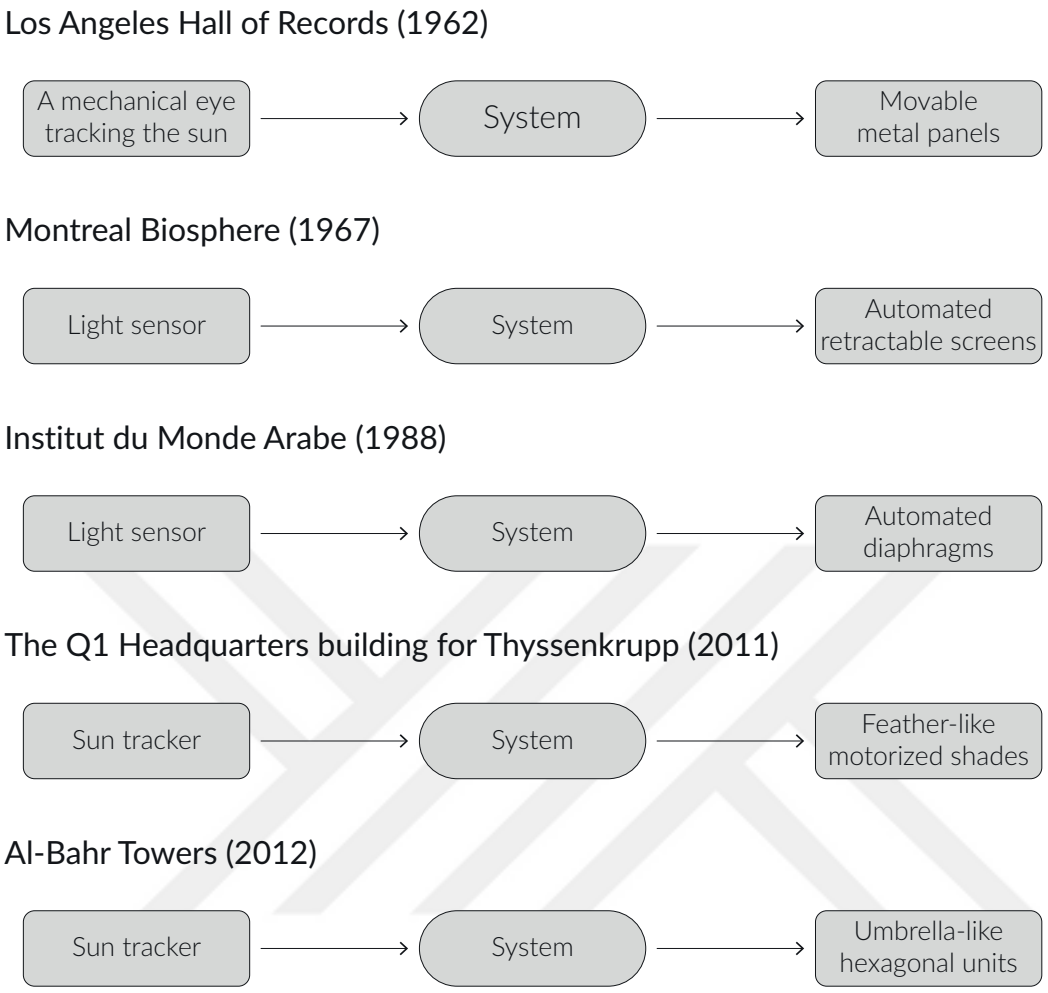

Figure 2.13 : System diagrams of the *Los Angeles Hall of Records* (1962) in Los Angeles [115], *Montreal Biosphere* (1967) [63], *Institut du Monde Arabe* (1988) [105], the *Q1 Headquarters* building for Thyssenkrupp (2011) [116], and *Al-Bahr Towers* (2012)) [116].

Thyssenkrupp (2011) in Essen and *Al-Bahr Towers* (2012) in Abu Dhabi are some applied buildings from this decade [114, 116] (Fig.2.13).

The precedents of sensing as a spatial ability were mostly utilizing the light sensors. As might be concluded from the mentioned applied projects, employing these devices are still relatively more common in the construction industry than other types. On the other hand, numerous experimental pavilions that employ other types of sensors with different sensing capabilities are also produced during the last two decades. *Aegis Hyposurface* (2001) by Mark Goulthorpe of dECOi Architect(e)s is one of the earliest examples of applying complex sensor systems to create a surface capable of responding to distinct types of stimuli separately [122]. In addition to responding to the changes in

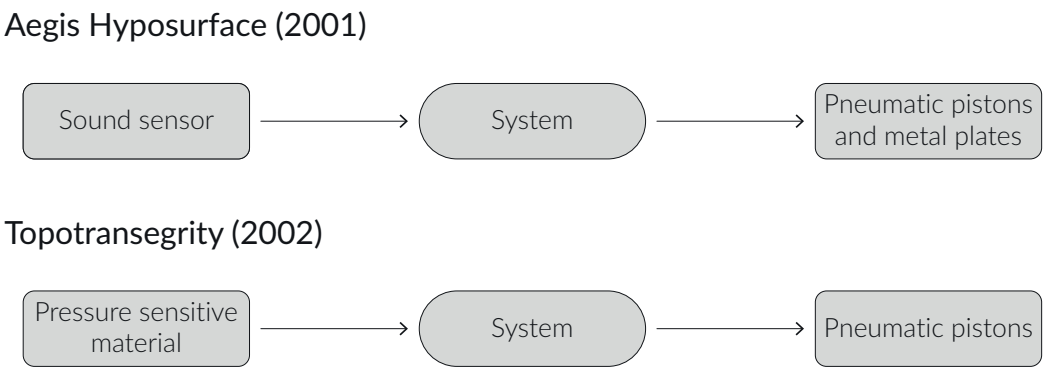

Figure 2.14 : System diagrams of *Aegis Hyposurface* (2001) [100], and *Topotransegrity* (2002) [123].

light levels as previously mentioned examples do, this pavilion can be programmed to change its geometry in response to people's movements or sound, but only one of these three at a time [61,100] (Fig.2.14). With similar innovative motivation, *Topotransegrity* (2002) by 5Subzero benefits from pressure-sensitive materials to drive an adaptive public space (Fig.2.14). As well as being able to run automatically, this prototype is also open to being pre-programmed by the architect directly [123, 127].

In the following decade, several architects carried such ideas a step further by implementing a wide variety of sensor types to their designs. Resinance project series (2013) by Manuel Kretzer [99, 111] is only one of the examples of this advancement. This project series consists of two installations; Resinance and Resinance 2.0. Through these projects, Kretzer and his team revealed the potential of various sensing methods. In Resinance, the project team benefitted from piezo vibration sensors to measure human interaction [54]. Besides, in Resinance 2.0, a metallic mesh is employed as a capacitive proximity sensor[9] [6]. Although they seem like utilizing a completely similar system scheme, Resinance and Resinance 2.0 differ from previous examples by converting the input into multiple reactions. Since it is the predecessor of this series, it would be more relevant to explain this attribute by explaining the actuation capabilities of Resinance. Primarily, each of the 40 elements of Resinance was capable of changing

[9]In addition to the touch sensing systems, the temperature sensors are also utilized in *Resinance* and *Resinance 2.0* [6, 99]. However, these sensors' primary role was delivering the data to the *actuation* system to keep it work stably and as expected. So, they were related to the *actuation* phase of the *adaptation*, rather than the *sensing* process. Therefore, it would be inaccurate to mention these projects under the same subcategory, together with those that utilize multiple sensor types to adapt to their environment.

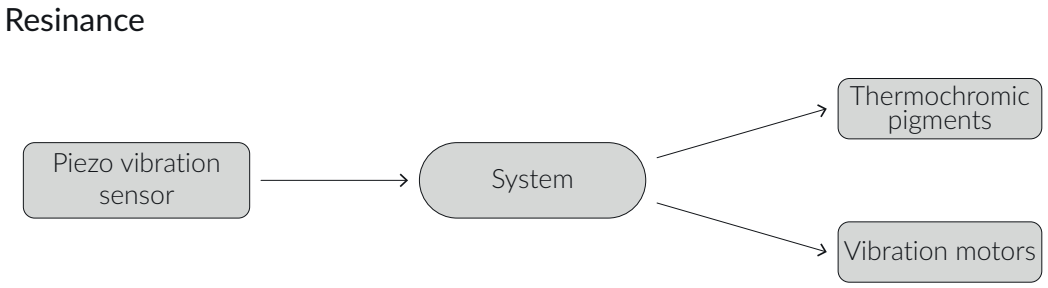

Figure 2.15 : System diagram of *Resinance* (2013) [54, 133].

their surface color through thermochromic pigments[10] in reaction to touch. However, these pigments were not producing an instant change. Therefore, vibration motors were implemented to the actuation system of the project to shiver the units [133] (Fig.2.15).

Even though the unit count in their sensor networks and the types of utilized sensors vary depending on their system's requirements, all these examples operate only a single type of sensor at a time. From this perspective, the *Media-TIC* building (2011) in Barcelona by Enric Ruiz-Geli of Cloud 9 and *Gardens by the Bay* (2012) in Singapore by Wilkinson Eyre Architects are original by employing multiple types of sensors to obtain climatic data. For instance, the *Media-TIC* building's control system detects changes in temperature, humidity, and air pressure [112] (Fig.2.16). Similarly, the sensor system of *Gardens by the Bay* can sense light levels, humidity, and temperature simultaneously [116] (Fig.2.16). Both of these buildings moderate the sunlight illuminating the interior space in accordance with the data collected through their mentioned sensor systems.

In addition to these building-scale examples, designs that utilize multiple types of sensors simultaneously are also practiced during the 2010s. Dune 4.2 (2010) in Rotterdam by Daan Roosegaarde of Studio Roosegaarde [132] is an earlier example of such projects from this period. This pavilion senses the "disturbance in the form of noise, agitation, or movement" through microphones and presence sensors [132] (Fig.2.17). Similarly but more experimentally, ExoBuilding (2012) by Schnädelbach utilizes various sensors to collect three distinct data related to the user's psychology.

[10] As Kretzer explains, *"Thermochromism is the property of a substance to reversibly change its color and/ or optical characteristics in response to a change in temperature"* [54].

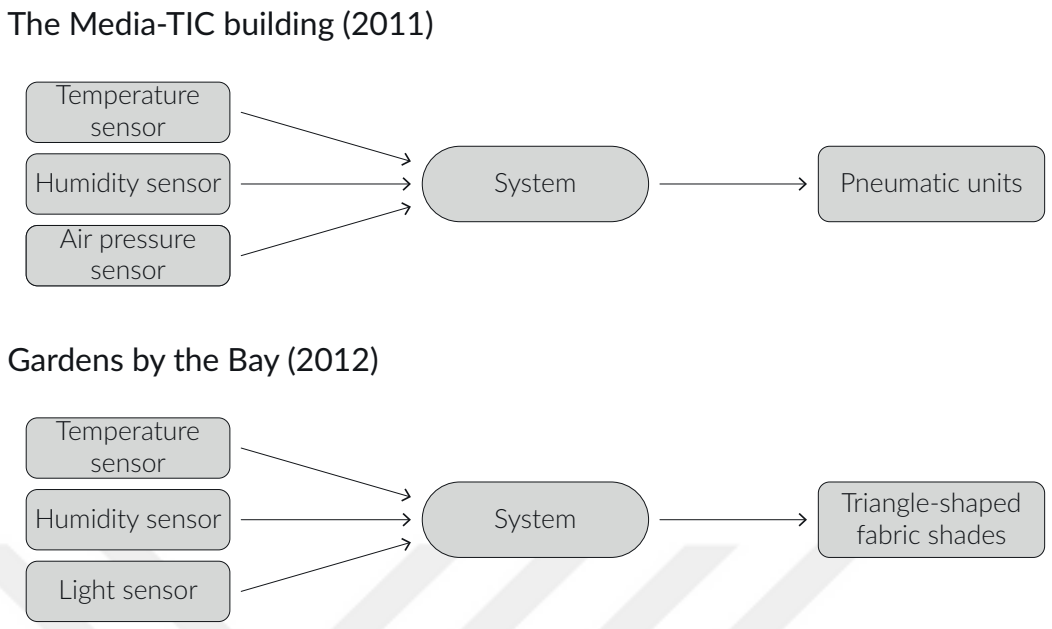

Figure 2.16 : System diagrams of the *Media-TIC* building (2011) [112], and *Gardens by the Bay* (2012) [116].

They are electrodermal activity (EDA), respiration (RSP), electrocardiogram (ECG) [131]. Similar to Kretzer's Resinance, this adaptive prototype responds to the stimulus with more than one kind of actuation. ExoBuilding responds to ECG through heartbeat sound and LED lights, the amplitude of abdominal breathing with movement, and EDA through a graphic projection on itself [131] (Fig.2.17).

Even though sensor-based examples dominate as a sensing method by number, advancements in material technologies made different strategies possible too. Especially during the last decade, architects found the opportunity to employ smart materials in their prototypes and pavilions. As Kretzer states that *"Smart Materials are fundamentally different from traditional materials since they are dynamic and active, which means that they operate within a predefined, often non-linear range, rather than just one particular setting"* [146]. This approach differs from the other two by the relationship between the sensing and acting processes. These two steps are entirely interwoven in material-based sensing because smart materials are responding to a stimulus through their inherent features. In brief, the active materials are both sensors and actuators [147]. By this means, such systems do not consume energy [114]. However, these materials respond to stimuli collected only from the close surrounding, such as humidity and heat [20]. Due to this limitation, it would not be inaccurate to

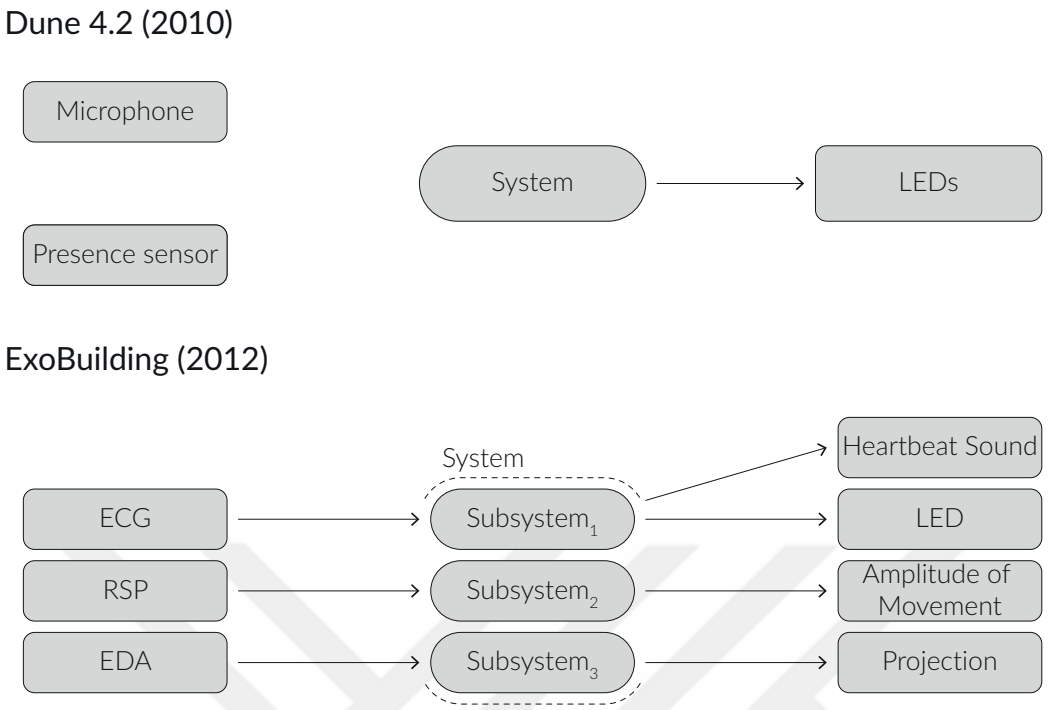

Figure 2.17 : System diagrams of *Dune 4.2* (2010) [132], and *Exobuilding* (2012) [131].

conclude that this method does not fit all building types. For instance, when it comes to designing a public space connected to the whole city, this feature might be considered a disadvantage.

Bloom (2011) by Doris Sung of DO|SU Studio Architecture in Los Angeles [20] and Hygroskin (2013) by Achim Menges and his team [114] are two well-known applications of employing active materials to interact with the surroundings through them. Hygroskin utilizes hygroscopic wood's capability to respond to the changes in humidity [22] (Fig.2.18). With similar motivation, Bloom consists of bimetallic strips that bend in reaction to temperature changes on the material's surface [148] (Fig.2.18).

At this point, it is essential to underline that not all projects that utilize smart materials can be categorized as material-based sensing examples. It is possible to find several examples that employ such materials to benefit from their lower energy consumption. For instance, Chin Khi Khoo's responsive façade prototypes employ shape memory alloy (SMA) units carried by a tensegrity structure [55, 56]. Also, Manuel Kretzer's ShapeShift consists of electroactive polymer panels [150]. However, despite being valuable by showing the potential of smart materials from an original

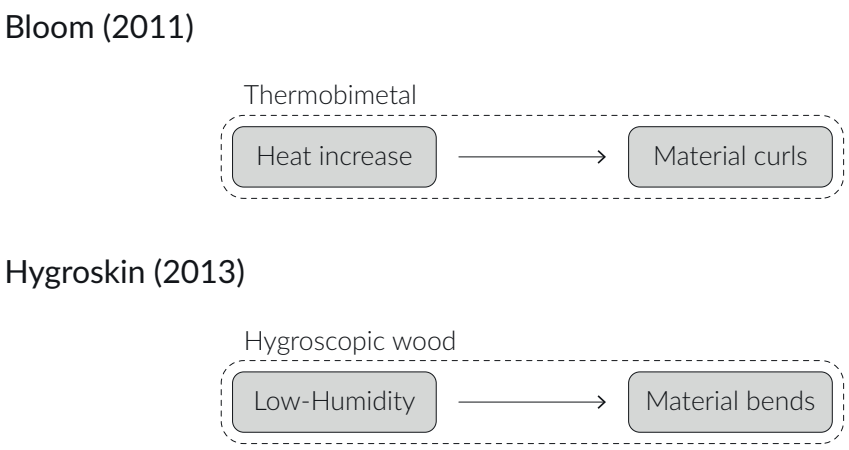

Figure 2.18 : System diagrams of *Bloom* (2011) [149], and *Hygroskin* (2013) [22].

aspect, these examples sense through external devices, not the material's inherent capacities. Therefore, it would be more accurate to categorize the sensing strategy employed in these and comparable examples not as material-based but as sensor-based.

In addition to these relatively more applied methods, since the late 1960s, architects and researchers have been testing mobile equipment's data collection potential to provide interaction [75]. Even though they were based on primitive signaling devices, the discussions based on these experiments were the first steps of a paradigm shift. Independently from these early prototypes, remote sensing technologies have been evolved rapidly during the following decades. Moreover, these developments are utilized in numerous distinct tasks [151]. In parallel with these technical advancements, unprecedented mobile devices, and online services extend the limits of social sensing with their abilities to collect a wide variety of data such as audio, image, location, motion, proximity, and text [152, 153]. As Wang defines, social sensing is *"the act of collection of observations about the physical environment from humans or devices acting on their behalf"* [154].[11]

As well as researchers working on other areas, architects have been seeking opportunities to implement these and comparable technologies to their profession. One of the earliest applied precedents of this approach is D-Tower (1998-2004) in

[11]Wang analyzes *social sensing* under three categories; *participatory sensing*, *opportunistic sensing*, and *social data scavenging* [154]. However, this subcategorization is not included in this title to avoid a digression. Still, it is necessary to note that all projects analyzed under this title benefit from participatory sensing methods. As Wang summarizes, *"In participatory sensing, individuals are explicitly and actively involved in the sensing process, and choose to perform some critical operations (e.g., operating the sensors, performing certain tasks, etc.) to meet application requirements"* [154].

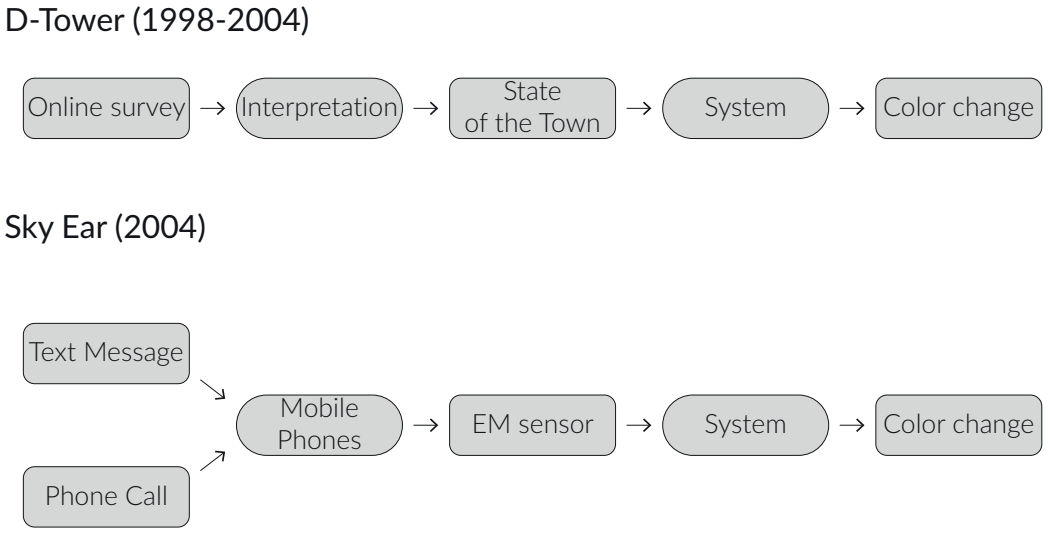

Figure 2.19 : System diagrams of *D-Tower* (1998-2004) [138], and *Sky Ear* (2004) [132, 155].

Doetinchem, the Netherlands, by NOX. Although it was not benefitting from mobile devices, this pavilion was using the data collected from volunteers through a website specially designed for the project and includes a comprehensive survey about the website's visitors' mood. By interpreting the answers, *D-Tower* was defining *"the State of the Town"* and switching color accordingly [138] (Fig.2.19). Similarly, *Sky Ear* (2004) by Usman Haque was also benefitting from data collected from the crowd. However, unlike *D-Tower*, this one-night installation was utilizing mobile devices instead of a website. During the performance, visitors asked to send text messages to and call the mobile phones implemented in the system of *Sky Ear*. Followingly, electromagnetic sensors of the installation detect the electromagnetic field produced by the GSM activity. Eventually, each balloon that forms Sky Ear adjusts their color through six LEDs placed inside them according to the increase or decrease detected by the sensors [132, 155] (Fig.2.19).

As a result of the increasing popularity of social network services, architects started to seek opportunities to realize approaches similar to D-Tower by collecting data through the APIs of social network services. Datagrove (2012) by Future Cities Lab at ZERO 1 *Seeking Silicon Valley 2012* Biennial is one of the precedents of implementing this brand new data source. In addition to utilizing proximity sensors, Datagrove collects data through Twitter and other social networks. Spontaneously, the pavilion

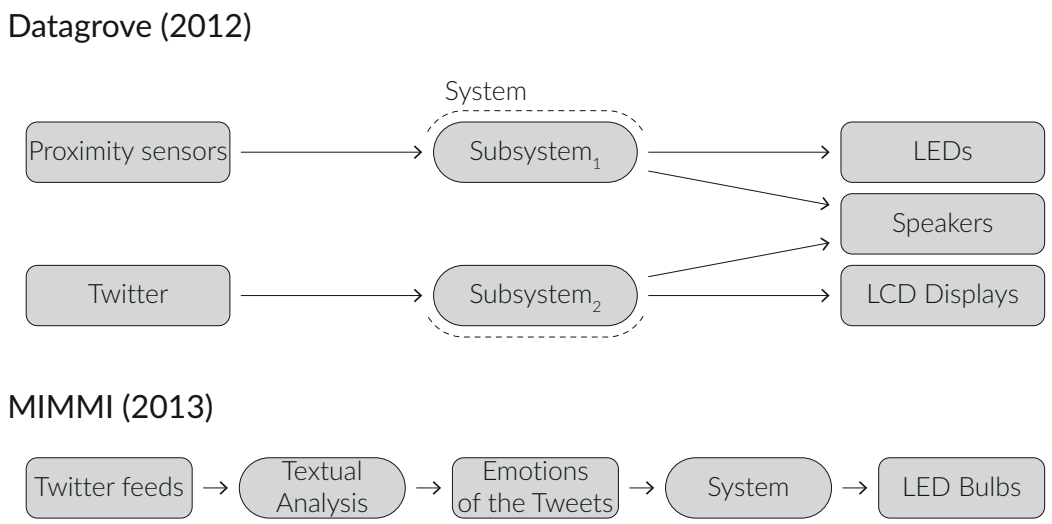

Figure 2.20 : System diagrams of *Datagrove* (2012) [132, 157], and *MIMMI* (2013) [132].

"whispers" the interpreted data to the visitors through the LEDs, LCDs, and speakers [132, 156, 157] (Fig.2.20). Similarly, *MIMMI* (2013) in Minneapolis by Invivia and Urbain DRC is also based on social network data. As Cantrell explains, *"MIMMI sourced information from local Twitter feeds and used textual analysis to detect the emotion of those tweets"* [132]. As a result of this detection, MIMMI responds to the positivity or negativity of the city's mood through *"a series of Wi-Fi-enabled LED bulbs and integrated misting system"* [132] (Fig.2.20).

Social sensing is employed as a sensing strategy in architecture rarely. On the other hand, recent research on data collected from social network services revealed its ability to recognize and analyze various urban phenomena. Regional functions [32–34, 37], mobility patterns [38, 39], temporal urban events [40], and specific urbanite activities [35, 36] are only a few of these focusses. When these topics' multifariousness is taken into account, it would not be inaccurate to note that social networks as a data source have a notable potential to provide valuable data for some specific building types such as public spaces. On the other hand, as might be noticed by the diagrams presented under this title, the systems of the projects that utilize social network data fit neither the process of active systems nor the passive strategies, as both presented by Lelieveld [29]. On that account, this thesis intends to propose a design process for social network data-driven adaptive architecture in the next chapter.

2.2.3 How to React?

As well as *sensing*, *actuation* is also a unique spatial capability necessary to fulfill the requirements of *adaptive architecture*. As appeared in both the *active* and *passive* processes proposed by Lelieveld, it is the last phase of *architectural adaptation* [29]. Briefly, an actuator is a component that converts the energy into the motion to form a reaction [114]. As seen in the early examples of *active building elements*, conventional approaches fall short of performing when a complex motion is required. Therefore, architects and researchers gravitate to newer technologies [56]. Thus, the cutting-edge techniques of its time affected and will affect the vision for this essential element of *adaptive architecture*. With an intention to comprehend the evolution of this relationship over time, several projects from a long period, starting from the 1960s until today, are analyzed under this title. In the literature, it is possible to find distinct categorizations dependent on the kinetic movement of the actuation mechanism or the type of equipment utilized in the actuator. However, using the terms *hard* and *soft* to categorize the approaches related to these up-to-date methods is dominant in recent literature [55, 158]. Therefore, the selected projects are grouped by their mechanical and robotic attributes as *hard* and *soft* under this title.[12][13] The distinct methods are going to be discussed by analyzing examples.[14]

Chronologically, instrumenting *hard* systems is a relatively earlier method of adding on buildings the skill of reacting. *Los Angeles Hall of Records* (1962) in Los Angeles by Richard Neutra is an early precedent of this collaboration. The façade of this exemplar benefits from aluminum louvers that can rotate in accordance with a sun tracking sensor on the rooftop. Thus, this project achieved more comfortable illumination and

[12] As Bauer summarizes, *"Hard robots are rigid- linked, with actuators for every joint. Soft robots on the other hand have actuators integrated and distributed throughout the robot"* [159] In addition to this explanation from the perspective of *robotics*, many architects and researchers are also benefiting from this terminology to describe their approaches. For instance, Khoo uses the term *hard* to define mechanical joints and components and *soft* to describe lightweight elastic composite materials [160]. In parallel, Abdelmohsen defines *soft* as *"less dependent on hard mechanical systems"* [161]. Similarly, Kim utilizes *soft* as an adjective to describe *"able to move without mechanical joints"* [162].

[13] As distinct from the definitions proposed by mentioned researchers, Till and Schneider utilizes the terms *hard* and *soft* to define the *indeterminacy* level of an *architectural space*. They briefly explain these two terms as *"soft refers to tactics which allow a certain indeterminacy, whereas hard refers to elements that more specifically determine the way that the design may be used"* [84].

[14] Before further analysis and discussion, it is essential to emphasize that this title is focused on buildings and pavilions that perform adaptation through *physical transformation*. Therefore, projects based on visual adjustments only, such as *D-Tower* (1998-2004), *Sky Ear* (2004), *Burble* (2006), *Datagrove* (2012), and *MIMMI* (2013), are excluded from this part of the study.

energy-efficiency [115]. Almost three decades later, *Institut du Monde Arabe* (1989) in Paris by Jean Nouvel was a breakthrough in the same technique with its scale and complexity provided by the sensors and embedded computational elements [105, 115]. The south façade of the institute contains 27000 diaphragms and 480 light sensors, which were designed to serve the surface to achieve a similar goal to Neutra's design [105].

It would be accurate to infer from these two exemplars that this approach relies on converting stable building elements to *dynamic* ones. However, these examples suffered problems related to friction [82] and caused maintenance difficulties [7], and more importantly, operational failures [105]. As a result, both of these precedents raised suspicion among the construction industry about the long-term reliability of similar systems and obstructed the industry-wide use of them [56]. Though this approach was unable to gain notable popularity, it has developed and improved over the decades. Eventually, several projects intended to benefit from the adaptive shading started to adopt these and comparable systems at the beginning of the 2010s. *Al-Bahr Towers* (2012) in Abu Dhabi, *Gardens by the Bay* (2012) in Singapore, and the *Q1 Headquarters* building for Thyssenkrupp (2011) in Essen are some of these buildings [114, 116].

As distinct from these applied buildings in scale, numerous architects pursued a similar goal of implementing the *active spatial change* to architecture through *hard* mechanisms in pavilion-scale. *Aegis Hyposurface* (2001) by Mark Goulthorpe of dECOi Architect(e)s [122] and *Topotransegrity* (2002) by 5Subzero was featured in the *Latent Utopias* exhibition curated by Zaha Hadid and Patrick Schumacher [123] are only two earlier examples of such motivation. Both of these pavilions utilized pneumatic systems to perform the *actuation* [100, 127].

Independently of the arguments for and against, these projects intercalated dynamic building components in the agenda of architecture. So, these early feedbacks have not been discouraging for numerous architects, but motivating them to seek different opportunities. Thanks to the progress in *material science*, they have been able to discuss how to employ cutting-edge materials and *no-mech systems* in their branches [6, 55, 163]. In particular, during the last decade [20]. These new materials have a diverse range of eccentric capabilities such as changing shape, color, or

adhesion, emitting light, generating electricity, and exchanging energy and matter [164]. Anna Maragdouki defines the architecture which utilizes these advancements as *"the architecture that has the ability to transform over time by incorporating smart materials that undergo purposeful change in accordance to external, environmental or not, stimuli"* [20]. Also, Chin Koi Khoo highlights that *"responsive materiality offers an initial concept of movement and change in response to material properties rather than changes in mechanical components, such as actuated motors and gears, in the responsive kinetic architectural context"* [56].

Besides, architects such as Achim Menges, Chin Koi Khoo, Doris Kim Sung, and Manuel Kretzer took the topic further through prototypes and pavilions. Maragdouki categorizes these works as *"material = part"* and *"material ≠ part"* [20]. With the help of her analysis, architectural skins prototyped by Chin Koi Khoo can be considered as *"material ≠ part"* with their *shape memory alloy* (SMA) units carried by the tensegrity structure [55, 56]. By virtue of this hybrid system, Khoo's façade proposal fulfills similar goals to the ones that were aimed by the *Los Angeles Hall of Records* and *Institut du Monde Arabe* too. Furthermore, as might be expected, the components of this kind are not suffering disadvantages caused by friction as encountered in mechanized ones [165].

In addition to Khoo's pioneering façade design, the variety of these newly emerging materials' skills gave architects a chance to shift the paradigm and test spatial scenarios that are not tested before. *Electroactive polymers*, *hygroscopic wood*, *bimetallic strips* are only a few *"material = part"* examples of these materials capable of reacting to a specific stimulus [20]. *Hygroskin* (2013) by Achim Menges and his team is one of the well-known precedents of instrumenting such materials. The installation was benefitting from the hygroscopic behavior of plywood. By doing so, it became capable of responding to humidity through elastic bending [22]. Another exemplar for this approach is *Bloom* (2011) by Doris Sung of DO|SU Studio Architecture in Los Angeles [20]. As distinct from Hygroskin, this pavilion was taking advantage of *bimetallic strips* that were bending as a reaction to the thermal changes. So, the active panels were shifting their shape during the different periods of the day, in compliance with the sun's position [148].

In short, the dynamic building components have come a long way since the 1960s. Still, it is necessary to admit that both *sensors* and *actuators*, in other words, the hardware of architecture, are still not flexible enough, at least not as much as the software of *active systems* in architecture [82]. Nevertheless, it would not be inaccurate to mention that the recent research and practices on the subject are promising. Especially, installations utilizing *electroactive polymers* such as Phototropia (2012) by Pantazis and Kretzer [20] are encouraging by the material's capability to be actuated by a wide range of data as long as they are translated into the electricity [111].

3. A DESIGN PROCESS FOR ADAPTIVE PUBLIC SPACES

Each original paradigm in architecture, such as *multi-machine fabrication* [166], *swarm formation* [167], *virtual reality* [168], and *parametric design* [169], requires to be conducted through a specific design process. Because of its unique core and elements, the same necessity goes for *adaptive architecture* too. Especially in design projects which employ complex data obtained from the social network services, this need is more visible. As explained in the previous chapter, *adaptive spaces* that utilize such data are distinct from other concepts of *spatial change* as well as conventional design methods. It would be reasonable to state that this contrast results from the autonomous and repeated collection and interpretation of data to lead the *space* to adapt to changing conditions continuously.

By taking this notable distinction into account, this research considers the design process of *social network data-driven adaptive architecture* as a data flow. Accordingly, the essential goal of this chapter is to implement the well-known *Data, Information, Knowledge, Wisdom Hierarchy* (DIKW) to the design process of the concept. *DIKW Hierarchy* is a knowledge management method developed, discussed, and practiced widely since the early 1950s [47, 170]. Principally, this study analyzes four members of this approach on an individual basis as they are defined in the literature and seeks terms used by architects to express similar elements in their study. By doing so, the structure of the design process is illustrated through the terminology of architecture.

The concept of standardizing *knowledge management* practice dates back to the late 1950s. However, these first ideas were away from accomplishing to propose a complete scheme [170]. Especially starting from the 1970s, these pioneering efforts were followed by several viable definitions of *data*, *knowledge*, and *information* and broad explanations of their relations. Eventually, beginning from the early 1980s, several researchers introduced various original hierarchies with different names such as *Knowledge Hierarchy* and *the T.S. Eliot Hierarchy* [47]. In the late 1980s, Zeleny

and Ackoff employed *DIKW Hierarchy* to name their approach [171]. This research focuses on both of the concepts and descriptions proposed by these two researchers to provide a sound basis for further steps of this chapter.

As Williams [47] and Rowley [49] states, Ackoff describes the elements of the DIKW hierarchy as below:

- *"Data are symbols that represent properties of objects, events and their environment. They are the products of observation."*
- *"Information is contained in descriptions, answers to questions that begin with such words as who, what, when and how many. Information is inferred from data."*
- *"Knowledge is know-how, for example, how a system works. It is what makes possible the transformation of information into instructions."*
- *"Wisdom adds value, which requires the mental function that we call judgement."*

In addition to this set of detailed definitions, Zeleny explains these terms from *data* to *wisdom* through their management as muddling through, efficiency (measurement and search), effectiveness (decision making), and explicability (judgment) [172].

Both Ackoff and Zeleny offer an additional level for the *DIKW hierarchy*. Ackoff proposes *understanding* between *knowledge* and *wisdom* [48], while Zeleny adds *enlightenment* beyond the *wisdom* [172]. However, neither of them are included in this research because of not being commonly used in the literature. Also, *wisdom* is excluded from this study due to the discussions about the possibility of performing it through computational processes [48] and limited explanations in the literature on it [49]. So, this thesis intends to implement *data*, *information*, *knowledge* phases to the design process of adaptive architecture and explain the operations which are necessary to convert each step to the next one.

This research names these three phases as *data*, *stimulus*, and *adaptive space*. Through considering the essentiality of the conversions between them, two steps are added to the proposed process too. They are *interpretation* between *data* and *stimulus*, and *simulation* between *stimulus* and *public space* (Fig.3.1). As they are implied in this research, the contents of these three phases are as below;

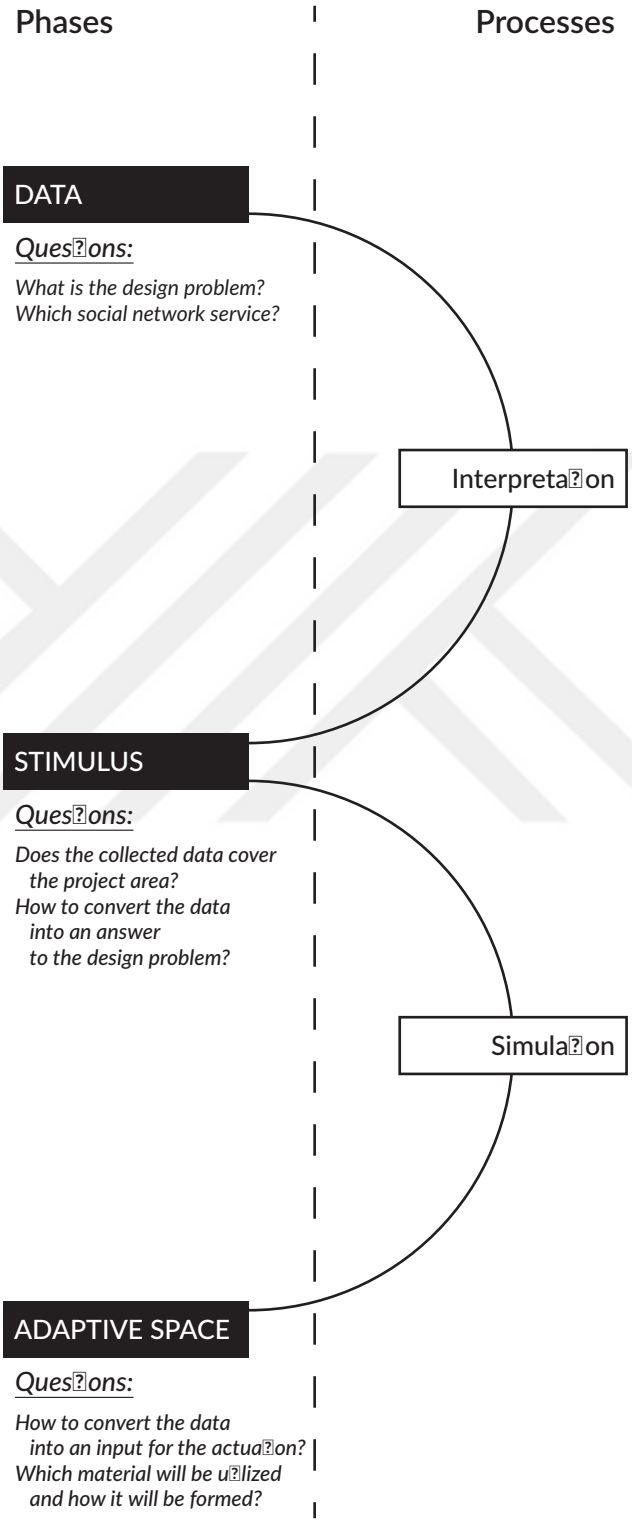

Figure 3.1 : Design process for social network data-driven adaptive public architecture.

- *Data* consists of symbols about the surroundings of the project area. Its scale may vary from the project area's itself to the whole city,
- *Stimulus* is produced through the *interpretation* process and provides the answers to the design problem which is defined by the architect,
- *Adaptive space* contains the knowledge of how to adapt to the surroundings in accordance with the *stimulus*. This knowledge is produced as an outcome of the digital and physical *simulation*.

This structure that consists of three distinct phases might seem similar to the processes proposed by other researchers. For instance, Khoo utilizes a process that contains *sensing*, *analysis*, and *actuation* during the design of morphing skins [30,31] (Fig.3.2). Similarly, Lelieveld describes the components of active systems as *external stimulus*, *system*, and *action/actuation* [29] (Fig.3.2). However, despite containing three phases similar to the process proposed by this research, these approaches do not cover the whole phases mentioned under this title. Most significantly, none of these models analyze *data* and *stimulus* separately. Because of the complexity of the social network data, considering these two phases on an individual basis and explaining the *interpretation* process that converts the *data* into the *stimulus* are found necessary within the context of this research.

3.1 Data

By considering the design process of *adaptive architecture* as a data-flow operated autonomously and repeatedly, choosing the data source is the first step of the process by being the initial point of the whole flow. At this stage, the architect has to decide which social network service will be used for the design. While making this essential choice, several circumstances such as the popularity of the service in the city where the project site is located, the content which is provided by the *application programming interface* (API) of the chosen social network, and the compatibility of this content to the design problem should be considered.

Recent studies reveal the potential of location-based social network (LBSN) data for analyzing urban phenomena in various aspects [173, 174]. Alternatively, utilizing different social networks such as Twitter and Facebook to analyze the project location

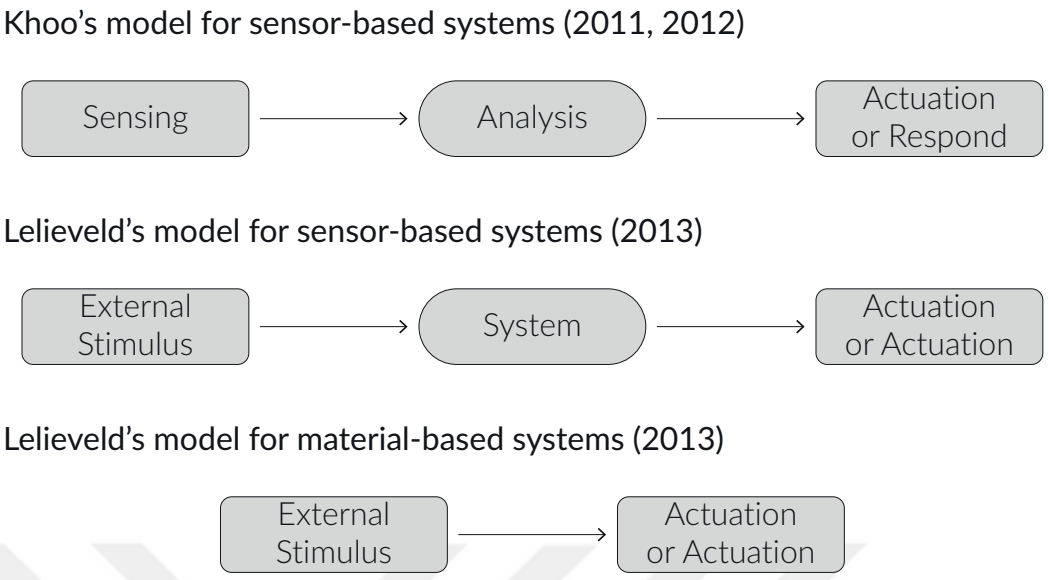

Figure 3.2 : System schemes for sensor-based and material based systems by Khoo and Lelieved [29–31].

contextually is possible. Recent research revealed that it is possible to recognize and analyze a wide variety of urban phenomena is applicable through the data gathered from such social networks. Regional functions [32–34, 37], mobility patterns [38, 39], temporal urban events [40], and specific urbanite activities [35, 36] are only a few of these topics.

Precedents such as *Datagrove* (2012) by Future Cities Lab at ZERO 1 *Seeking Silicon Valley 2012* Biennial [156] and the *Minneapolis Interactive Macro-Mood Installation* (MIMMI) (2013) by Invivia and Urbain DRC [132] employ datasets of this kind. Using multiple datasets starting from the first step or combining a single dataset with another by the interpretation process can also be considered by the architect. At this point, it is necessary to note that such strategies would be relatively more complex and require the assistance of a data scientist.

3.2 From Data to Stimulus

The process between *data* and *stimulus* is directly dependent on the *sensing* strategy utilized by the *adaptive space*. As it is employed in the suggested design process, the *interpretation* step of the social network data differs from *sensor-based* and *material-based* systems by being significantly more complex. Material-based sensing systems employ smart materials that perform as both sensors and actuators

simultaneously [147]. Thus, it is not possible to recognize a separate *interpretation* step in this approach. Different from this model, the *sensing* and *reacting* phases are divided in *sensor-based sensing* [30, 31]. Thus, architects have a chance to focus the system on a particular *external stimulus*, which will be employed in the *spatial adaptation* by choosing the equipment from a wide range of sensor types [145]. As a result of this significant advantage, a multi-layered *interpretation* process to reach a suitable *stimulus* is not required by the *sensor-based* systems. In parallel, architects such as Khoo and Leileveld categorize both *data* and *stimulus* under the same component without mentioning an *interpretation* process [29–31]. Because such complex computation is not required by any of these two strategies.

On the other hand, the data obtained from the regular APIs of social network services include various data types with multifarious content. For instance, *Next Venues* endpoint of Foursquare's API returns data about five venues visited after a specified venue. Still, the *JavaScript Object Notation* (JSON) file obtained from the API contains a wide variety of data such as id, name, coordinates, address, distance to the initial venue. These data are delivered in different data types such as *dictionary*, *list*, and *string* [175]. Therefore, an architect has to develop a significantly complex *interpretation* process to convert the collected *data* to the *stimulus* that answers the design problem determined in the previous steps of the design. The components of this computational process depend on the collected *data* and the targeted *stimulus*.

Considering that both data types and design problems can vary in accordance with the architect's decisions and the project's necessities, it is essential to note that the *interpretation* process can significantly change in different projects. For instance, in a project that utilizes the textual data collected by Twitter, natural language processing (NLP) pipelines could be necessary to interpret the dataset and transmit an adequate *stimulus* to the further steps of the design process. It is also essential to note that even though such system schemes require a complex computation, they allow architects to modify the system whenever needed or desired without changing any part of the electrical circuit of the system. Because, in principle, the *interpretation* process is software. Thus, it is open to be updated.

3.3 From Stimulus to Public Space

Despite providing refined and valuable information for *spatial adaptation*, the *stimulus* does not include the *knowledge* of how to physically respond to the content delivered by itself. Therefore, an additional process that converts the *stimulus* into the *knowledge* is required by the *adaptive space*. Unlike the phase named *data* and the step named *interpretation*, this process is mentioned in the design processes proposed by other researchers as *analysis* or *system* [29–31]. This step is called *simulation* by the thesis to indicate both digital and physical prototyping and tests.

At this part of the design process, the architect decides which material can provide the physical capabilities required by the project. Physical and digital prototyping is essential to supplement this decision. Recent research revealed the potential of the combination of these prototyping approaches [176]. After the material choice, the architect defines the rules to build the conversation between the *stimulus* and *public space* when the architectural project is constructed. The process of defining the rules are driven by several factors such as aesthetic goals defined by the architect, the requirements of the project and the project site, limits of the selected material, and regular limitations. Considering that *simulation* is the last step of the design process before the *adaptive space* and its construction, the architect may change some decisions made in the previous steps of the workflow by the experience obtained through this comprehensive step.

Unlike other steps of the process, some parts of the *simulation*, such as the material choice, the unit geometry, and the installation of the electrical circuits, can not be repeated by the *adaptive space*. Therefore, taking opinions of experts from the other branches such as *material engineering*, *electronics*, and *soft robotics* would be beneficial to manage a more successful process and get more promising results. Still, it is essential to note that the computational rules that constitute the conversation between the *stimulus* and *adaptive space* can be updated if required or desired.

4. CONCLUSION

Through this thesis, it is intended to propose *a design process for social network data-driven adaptive architecture*. However, focusing only on this primary goal would be lacking to discuss the topic extensively. Thus, this research starts with two preparative steps. These phases are proposed under the second chapter, and they are titled as *understanding adaptive architecture through terminology* and *elements of adaptive architecture*.

In the first part of the second chapter, the study focuses on understanding the primary goals and originalities of *adaptive architecture*. For that purpose, along with the term *adaptive*, four different concepts of *change* in architecture and their backgrounds are analyzed. These notions are *flexible*, *adaptable*, *responsive*, and *interactive*. Being related to *adaptive architecture*, as they are used in the literature, is assigned as the selection criteria at this step. Together with these terms directly related to the term *adaptive*, concepts such as *evolutionary*, *manipulative*, and *transformable* and spatial attributes such as *variability* and *sensing* are also mentioned under this title. By doing so, this part of the study is aimed to provide a comprehensive analysis of the terminology.

Even though definitions and backgrounds of these concepts are also mentioned in this part of the thesis, the main objective of this extensive analysis is not understanding these five notions individually, but indicating particular distinctions between them. However, as revealed by the title based on a broad literature review, entirely separating any of these terms from the others is almost unachievable due to the terminology's interwoven structure. Still, numerous similarities and contrasts among these five terms are mentioned as other architects, and researchers point them. In light of their studies, a consistent framework for each one of the sifted five terms was drawn under this title.

The primary motivations of *adaptive architecture* constitute the product of this subchapter. As analyzed during this part of the research, *adaptive space* intends to provide spatial variability by sensing its surroundings and performing an *active*

adaptation. Some of these characteristics are shared by other concepts, such as *adaptable* and *responsive*, too. Therefore, it is essential to note that the originality of the term *adaptive* is being aimed to deliver all of them simultaneously.

In the following subchapter, various approaches to catalog the elements of *adaptive architecture* are analyzed. As an outcome, the fundamental questions of this concept are listed as *"what to adapt," "how to sense," "how to react."* Followingly, the categorizations by other architects are combined with several applied projects to define different answers given to these questions. The number of analyzed projects is limited since the primary objective of this part of the study is not explaining every single project in the history of *active spatial adaptation*, but developing a solid list of strategies on the subject.

As they are proposed under related titles, the strategies are *adapting to the climatic conditions* and *adapting to the behavior of people* to *"what to adapt," sensor-based sensing*, *material-based sensing*, and *social sensing* to *"how to sense,"* and *hard systems* and *soft systems* to *"how to react."* Each approach is explained through multiple projects with distinct motivations. As indicated by this subchapter, *adapting to the climatic conditions*, *sensor-based sensing*, and reacting through *hard systems* are relatively more common.

In addition to opening different methods to the discussion, this title is essential for the thesis by revealing how initial is the *sensing* process for other steps of designing an *active space*. As this part of the thesis explains in detail, as a result of the answer given to the question *"how to sense,"* additional steps might be needed to provide the *spatial adaptation*. For instance, while *material-based sensing* does not require an external *sensing* system, *social sensing* needs additional computational processes to interpret the data and convert it to meaningful information for the *architectural space*. This distinction sets the basis for the third chapter that is aimed to introduce *a design process for social network data-driven adaptive architecture*.

The third chapter is principally the core of the study. Under this title, *a design process for social network data-driven adaptive architecture* is proposed. In the literature, it is possible to find several design processes for *sensor-based* and *material-based adaptive spaces*. As architects and researchers state, *sensor-based sensing* consists of three

steps; *sensing*, *analysis*, and *actuation*. On the other hand, *material-based sensing* does not require an additional *analysis* step as the material senses the stimulus through its inherent attributes [29–31].

However, these approaches do not cover the necessities of collecting and interpreting social network data. With an intention to provide a fit design process, this research discusses the problem around the *information management* paradigms. Therefore, the well-known *data, information, knowledge, wisdom hierarchy* (DIKW) is employed to develop a process that explains the state of information and defines the conversions between them adequately. This approach constitutes the novelty of this work.

Before converting the *DIKW hierarchy* into an architectural design process, *wisdom* is excluded from this study due to the discussions about the possibility of implementing it to computational processes [48] and limited explanations in the literature [49]. Thus, the proposed design process is structured as a three-step flow that consists of *data*, *information*, and *knowledge*. This study names these steps as *data*, *stimulus*, and *space* to combine them with the terminology of architecture. The conversions between these three phases are added to the proposal as two processes. They are the *interpretation* between *data* and *stimulus*, and the *simulation* between *stimulus* and *space*.

4.1 Discussions and Future Projections

According to the researcher, the most remarkable advantage of an *adaptive space* designed through the proposed process is allowing the architect to change the data source and update the *interpretation* process without changing any part of the electronic circuit of the project. So, the architect may continue improving the system whenever needed, even after the construction is completed. However, both sensors and actuators, in other words, the hardware of such architecture, are still not flexible enough, in comparison to the software side [82]. Although employing social network data rather than sensors eliminates the incapabilities of *sensor-based sensing* systems and provides several advantages, as mentioned before, it comes with its unusual challenges. Because social network services do not collect and store data with the same interests as architects. Hence, using the data obtained through the APIs of these services in design requires a complex computation process. This situation might be seen as an unmasterable problem. However, in parallel with several architects [177],

the researcher sees it as beneficial stress to push architects interested in this topic to collaborate with related branches within the context of architecture.

Additionally, Brand states that *"ALL BUILDINGS are predictions. All predictions are wrong"* [5]. When his words are taken into account, it is necessary to highlight social network data's potential to increase architects' predictive capacity. Today, utilizing such technologies might be seen as a design choice. However, by considering the fluxional essence of our era, it would not be inaccurate to conclude that it will be a necessity in the not too distant future. Therefore, As Megahed mentions too, architects have to develop new skills to *"explore, consider, and design"* [64] such architectural systems and to meet the requirements of an interdisciplinary design ecosystem. As these technologies already commenced to modify the *urban fabric* significantly, Goyal commentates that;

> What is to be seen is how fast the profession of architecture could adapt and evolve to such scenarios and reposition its role as a catalyst to progress the urban condition, from designers of objects to design who mediate the 'system for objects'. [178]

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