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Exploring the Potential Impact of Biobuilding Components into Building Design: An Experiment in Architectural Design Studio

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ABSTRACT
The recent technological advancements introduce the incorporation of living and manufactured components within a variety of innovations such as autonomously growing furniture, self-healing building materials, wearable technologies, and many more. In this paper, these innovations, incorporated with living organisms, are entitled as 'biobuilding' components (BBC). The paper aims to explore their possible integrations into building design, particularly in architectural education. Within the scope of the research, the influence of BBC on building design is explored firstly by literature reviews, and then carrying out a design experiment with first-year architecture students in an architectural design studio. The design experiment leads us to examine the integration of BBC in building design by their introduction into the design process. The findings, based on the work of the students, author notes, and retrospective reports of the student presentations, give insights into the potential impact of BBC on building design especially on the creating relationships between human, product and building. Furthermore, they point out the changing roles of the architects in the near future. Therefore, the paper concludes that architecture students should be aware of BBC, and its possible influences on architectural discipline.

Keywords: Architecture design studio, Architectural design education, Building design process, Integration of technology, Biobuilding components

1. INTRODUCTION
Technological advancements enable us to create designs with living organisms instead of fabricating products inspired by them (Deuerling et al., 2018; Shu et al., 2011). Thus, to go beyond the mimicking of nature becomes possible in design disciplines (Myers, 2018). Possible examples could be pots cleaning air with plants, chandeliers purifying the air via bacteria, self-growing furniture made from mushrooms (Fig. 01). Likewise, wearable technologies such as; smartwatches, bracelets, and smart clothing unite with a living component: the human body. They all exemplify the incorporation of living organisms with manufactured components and indicate the 'blend' of the concepts of nature and technology (van Mensvoort et al., 2015). At this juncture, this phenomenon motivates us to explore its possible integrations into building design.


Clairy at Keukenhof Exhibition, NL, 2018


Mycelium based products at Officina Corpuscoli, Amsterdam, NL, 2019


Closed Loop Smart Athleisure Fashion at Atellier By-wire, Utrecht, NL, 2019

Figure 01 Examples of innovations exemplifying the incorporation of living and manufactured components**,** Source: Author's archive

Despite the growing interest in the phenomenon with the increasing number of innovations, there is no specific term referring to the incorporation of living organisms in the existing literature (Deuerling et al., 2018). In this paper, these innovations explained with the term biobuilding components which implies building components unified with autonomously growing and living components such as plants, protists, animals, and humans (Kirbas Akyürek et al., 2020). The goal of the paper is to examine the influences of biobuilding components (BBC) on building design by their integrations into the different building parts.

Firstly, a historical overview summarizes the role of (smart) technology on building design in the discipline of architecture, and contemporary studies explain the transformation of building components into biobuilding components. Therefore, the biobuilding component term is introduced as a result of the literature studies. Secondly, due to the critical importance of BBC for building design, the article applies a design experiment with first-year students in an architectural design studio. The experiment enables us to observe the design process of the integration of BBC on the different parts of the building, and its objectives are as follows:

- To analyze the relationship between the introduction of BBC in the design process and their integration.
- To explore the integration of BBC by affecting the dynamics between the interior to the exterior on a particular building part.
- To observe the approach of the architecture students towards upcoming products within architectural design.
- To determine the prevailing advances and concerns that encourage or hamper the integration of BBC.

At the beginning of the experiment, the students were divided into two groups as 'test' and 'control' based on the given time of biobuilding components in a different period of the same design process of a single-housing project. During the experiment, the student assignments: diagrams, sketches, graphs, hand-written memos, and models were collected and photographed, along with the notes of the author during the design process. To determine the affected building parts from the integration of biobuilding components into building design, the theory of Brand (1994), specifying six (6) layers in a building; 'site', 'structure', 'skin', 'service', 'space plan' and 'stuff', was utilized as an 'assistive tool'. The qualitative data gathered as the transcriptions of the verbal data of the student presentations were analyzed with Protocol Analysis (PA) method as the retrospective reports.

As a result, the experiment presented four (4) key results in line with the objectives of the experiment; 'different design approaches', 'associated and affected building parts', 'advances', and 'concerns' that either motivate or de-motive the integration of BBC. The

experiment also showed that the students in both groups choose either to integrate or exclude the given innovations. However, test group students were consciously aware of the reflections of the innovations on different parts of a building. Control group students, on the other hand, ignored the impacts of the innovations on their designs even though they integrated the given innovations into their designs. Overall, for both groups, the individual works of the students underlined the significance of the design approach towards the relationships among user, product and the building on the integration of BBC. To compare the findings from each group revealed the links between their introductions into the design process and the possible outcomes of BBC on different building parts.

2. A HISTORICAL OVERVIEW OF THE INTEGRATION OF THE SMALL-SCALE PRODUCTS IN BUİLDING DESIGN

Two significant leaps in technology come forward as foundations of the interference of technology into daily life. Firstly, the arrival of electricity into the home environment in the first quarter of the 20th century triggered the rise of domestic appliances, and subsequently HVAC systems in the buildings. Secondly, in the last quarter of the 20th century, developments in information technology present the possibility of exchanging information between people and household appliances, systems, and networks, inside and outside of the home (Aldrich, 2003).

At the beginning of the 20th century, the fundamental purpose of electricity was only considered as lighting, so only one socket seemed enough for one house (Harper, 2003; pp. 6). Between 1920-1940, the advertisement of domestic technologies promising less housework resulted in houses to have more electric sockets which increased the integration of technologies into daily activities as well as the home environment (Aldrich, 2003). Accordingly, house designs have begun to take shape around the advantages of the growing number of domestic appliances (Gann and Barlow, 1999).

By the 1940s, air-conditioned office buildings became a standard feature in the design of workplaces in the USA (Eisenbrand, 2006). In the 1950s office buildings and spaces were 'more mechanized' through the spread of computers at workplaces which also triggered the process of automation and the field of information technology. In the end, all of the technologies in the workplace were transferred into the home environment and shaped house designs (Hammink and Mohammadi, 2017).

In the 1960s, another domestic technology stream started to rise; time-consuming technologies such as television, radio, and computers spread rapidly (Hammink and Mohammadi, 2017). This rapid growth led to hobbyists trying to connect these technologies in their homes as 'wired homes' as the early concepts of smart homes which only become possible with the rise of computing and information technology (Harper, 2003). Following the growing potential of digital systems in daily activities, the term 'Smart Home' was first used in 1984 by the American Association of House Builders (Harper, 2003; Solaimani et al., 2011). What is crucial here is that the home was attributed as being smart not for their construction techniques or sustainable features, it was smart by including interactive and intelligent technologies (Harper, 2003; pp. 3).

Throughout history, many technologies, in different scales, have been integrated into buildings and triggered the designs of smart homes with more smart technologies. Today, designing with biology is the focus in several platforms and researches such as competitions, school programs museum exhibitions, conferences, and books (Myers, 2018; pp. 10-16). Current developments in biological sciences enable us to design with living organisms instead of fabricating products inspiring from it, thus to reach beyond biomimicry becomes possible (Myers, 2018). The merge of natural and manufactured elements may sound futuristic, obscure and unrealistic at first, but pieces of evidence from everyday life insist that this fusion has already started (Van Mensvoort, 2015). Thus, the

powerful innovations bridging the living and artificial world turn the ideas that were once confined to speculation into reality (Antonelli in Myers 2018; pp. 6-7). At this juncture, recent developments in technology indicate another transformation with the rise of BBC.

Indeed, academic and popular literature is overwhelmed with a wide range of approaches explaining the ways as such to connect, inspire, utilize and merge with nature. The terms have been using interchangeably as such: "biomimicry", "bio-inspired", "biomimetic", "bioinspiration", "biophilia", "biocentric", and many more (Benyus, 1997; Deuerling et al., 2018; Imani et al., 2017; Oguntona and Aigbavboa, 2017; Shu et al., 2011; Valdecasas and Wheeler, 2018). This variety in terminology underlines the growing interest and the importance of the phenomenon on the blending concepts of nature and technology. However, the lack of blanket term to define the incorporation between living and manufactured components bring complexity and misunderstanding. Therefore, this study examines eighty (80) different scholar and non-scholar projects. A variety of products as the incorporation of living and manufactured components, entitled with different terms, in different domains, scales, and functions and were collected. The 34% of examples are described through the customized term with 'bio' prefix as such 'bioconcrete', 'biobrick' and many more. Secondly, 20% of the samples are explained with their 'smart' features. In 18% of the samples, the terms related to 'living' is detected while in 17% terms related to 'growing' is used. To stress the unification of living and manufactured components, the examples are entitled as 'biobuilding components.' Then, conducts a design experiment that explores the potential of BBC on building design by integrating them into the design process.

3. THE DESIGN EXPERİMENT

The design experiment conducted in the architectural design studio of which architecture students were assigned to develop single-house designs. The applied methodology sets the organization of the experiment, the role of the actors and place, assigned technologies and data gathering, is elucidated. Further on, the experiment is explained with the results found in two phases; *Phase 01* (warm-up), and *Phase 02* (research).

3.1 Applied Methodology

3.1.1 Organization of the Design Experiment

The experiment was held between September 2018 to January 2019 with gender-equal group of sixteen (16) first-year architecture undergraduate students as a part of the first-year design studio project. The experiment coordinated with the project course weekly schedule (Figure 02). The experiment started with 'Phase 01' (warm-up) to introduce the background of the research to the students. Then, 'Phase 02' (research) was planned with two interferences into the design process by the introduction of the BBC in the different periods.

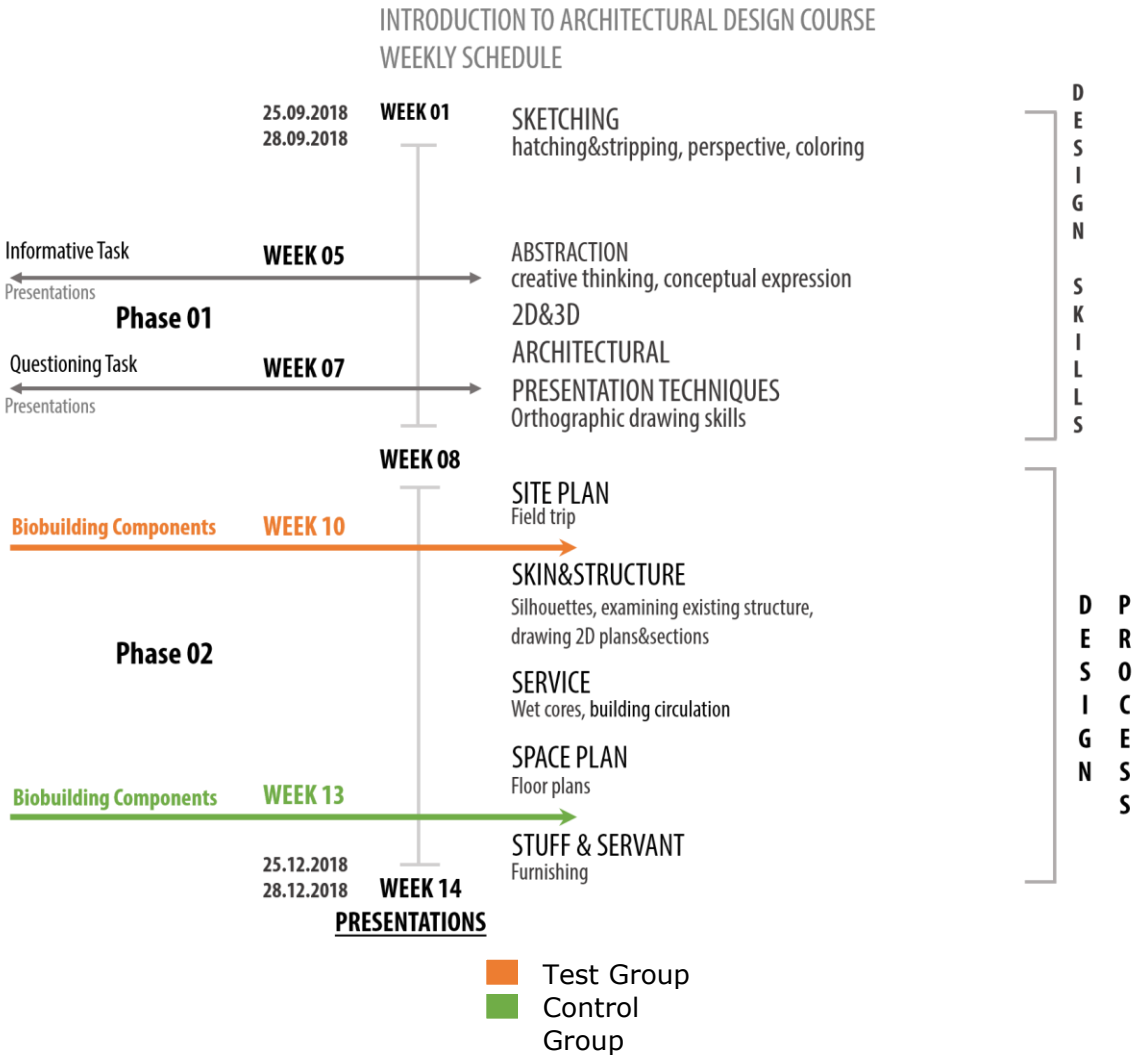

Figure 02 The weekly schedule of the project course

The experiment hypothesizes that the introduction of BBC at the early stage of the design process shall result in integrations into building design. Since the students have higher awareness and understanding of technological advancement, they are expected to integrate innovations into different building parts. Therefore, firstly, BBC were given to half of the students at the beginning of the design process. This group of students (test group) developed their final single-housing designs with the given BBC through the entire design process. Secondly, BBC were also given to the other half of the students (control group) at the end of the design process. Each student was tasked to present their final designs in relation to the given innovations. Control group students expected to exclude or partly integrate BBC, while test group students expected to integrate BBC into different building parts.

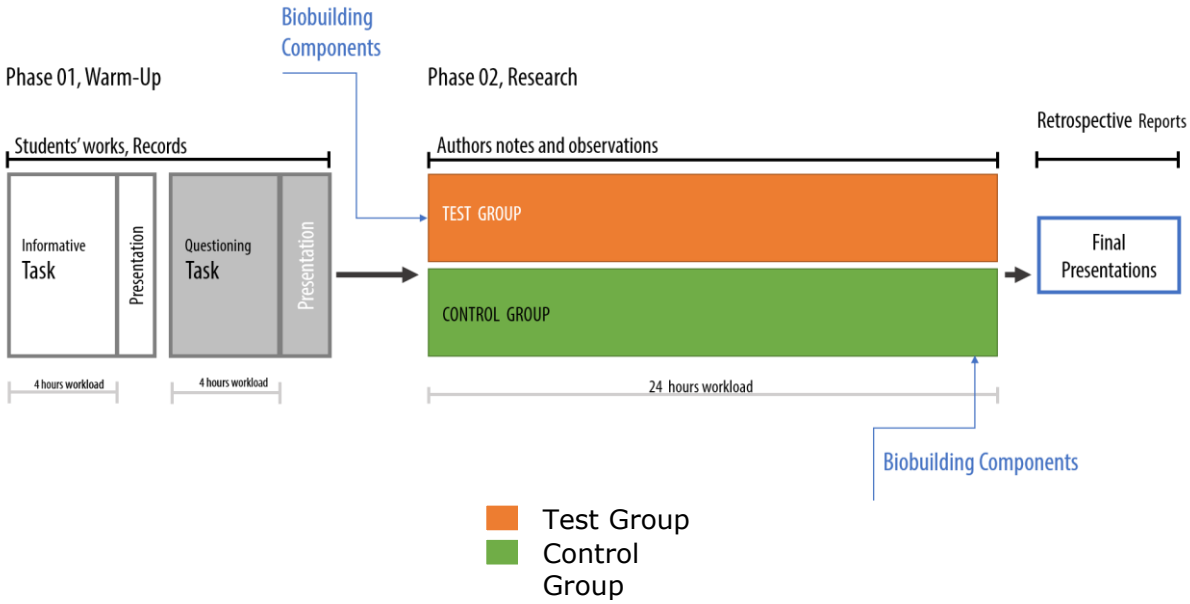

Figure 03 The organization of the experiment

3.1.2 The role of the actors and place

The primary motivation behind the selection of first-year students for this experiment is to draw attention to the changing roles of the architects soon with the increasing number of BBC. Moreover, to carry out the design experiment in the architectural design studio as a part of the first-year project course has brought four (4) significant advantages to the research.

- First of all, the architectural design studios represent the core of architectural education in which students try to bring solutions to several architectural design problems; contextual, climatic and programmatic (Çaglar, N. & Uludag, Z., 2006).
- Secondly, the architectural design studios embrace learning by doing approach by asking students to design even though they do not know what design indicates.
- Thirdly, the project course starts with developing basic design skills and later on introduces the fundamental steps of the building design process in particularly to housing design mainly focusing on the interior dynamics at home environment with a limited attention the urban context.
- Lastly, the course lasts fourteen (14) weeks that provides to observe the entire building design process instead of conducting a workshop in a limited time or the evaluation only the end product.

3.1.3 Determination of the affected building parts

To determine the affected building parts with the integration of BBC, the theory of Brand (1994) was embraced as an assistive tool. The building layers of Brand allow us to trace the established relationships between BBC and the buildings by showing the related building parts in the designs of the students. Brand (1994) divides an entire building into six different layers: Site (eternal), Structure indicates the foundation and load-bearing elements, Skin means exterior surfaces, Services includes communication wiring, electrical wiring, plumbing, HVAC, elevators, and escalators, Space plan refers to interior walls, ceilings, floors, and doors, and Stuff means chairs, desks, kitchen appliances, and lamps. The experiment concentrates on the interior dynamics at home environment, therefore the role of 'site' is limited in terms focusing the relationships between the context and the building. Furthermore, the layers also indicate a top down approach from site to stuff on both design and construction processes (Pushkar and Shaviv, 2016). As shown in Figure

02, in the *Introduction to Architectural Design* course students also follows the same process starts from 'site', and ends with 'stuff'.

3.1.4 Assigned BBC

Within the aforementioned (80) BBC each student were given randomly selected BBC that can originally be placed in 'stuff' layer determined by Brand (1994) (Table I).

Table I Assigned BBC

	#	Project	Function	Student
Test Group	1	Google Glass	Hands-free safety guidance device.	Student 01
	2	Living Light	An off-grid lamp powered by photosynthesis.	Student 02
	3	Mercury Heated Jacket	Smart clothing adjusting optimal body temperature.	Student 03
	4	Mushroom Chairs	3D printed mushrooms.	Student 04
	5	Grove Ecosystem	Indoor self-sustainable garden.	Student 05
	6	Bacterioptica Chandelier	A living&growing chandelier with bacteria.	Student 06
	7	Cicret Bracelet	E-skin project creates touch screen from your arm.	Student 07
	8	Mi.Mu Gloves	Gloves allow to compose music through movement and gesture.	Student 08
Control Group	9	Scroll Ring	A ring lets users easily interact with augmented reality.	Student 09
	10	Livesglass	To bring clean air to small spaces.	Student 10
	11	Drop by Drop	A plant base home water filtration system.	Student 11
	12	Polar Team Pro Shirt	To monitor the hearth rate and track fitness activity.	Student 12
	13	Clairy	Small-scale air filtration system.	Student 13
	14	Levi's Commuter Trucker Jacket	Smart clothing interacted with smart phone.	Student 14
	15	Nadi X, Smart yoga pants	Smart clothing with fitness guidance.	Student 15
	16	Ambio Lamp	Lamp using octopus bacteria.	Student 16

3.1.4 Data gatherings

During the experiment, the works of the students; diagrams, sketches, graphs, hand-written memos, and models were collected and photographed. The author observed the whole process and took notes systematically and continuously. Additionally, presentations of the students at the end of the assignments were recorded in audio and video.

The Protocol Analysis (PA) method selected to analyze collected verbal data in the experiment. PA is an observational research method of analyzing the behaviors of designers in empirical studies (Önal, 2015) by allowing to encode cognitive approaches and problem-solving abilities of designers (Cross and Keynes, 2001; Dorst & Dijkhuis, 1995). In this respect, the design disciplines such as industrial design, architectural design,

engineering design, and interior design have adopted the method as a valid research tool (Jiang and Ching-Chiuan, 2009).

PA is mainly divided into two approaches; concurrent (the report is collected during the task) and retrospective (report is collected after the task) protocols (Tversky and Suwa, 1997; Ericsson, K. A., Simon, 1980). Therefore, retrospective protocols were found appropriate in the framework of this experiment.

4. Exploring the Integration of BBC into Building Design

4.2.1 Phase 01, Warm-Up

The warm-up phase was found necessary considering the complexity and wider aspects of the issue. The objectives of the warm-up assignments were:

- To provide a discussion platform to the students on recent advancements of technology at the intersection of living and manufactured.
- To observe ideas and prejudices that hampers the creativity of the students on BBC.

This phase conducted in two tasks; informative (briefing) and questioning. Firstly, the students were divided into four random groups and one keyword given for each. The keywords; 'nature', 'technology,' 'integration,' and 'innovation' led us to open a discussion of the awareness of the students on increasing number of BBC, and their integration into everyday life. Each group tasked to conceptualize their keywords into 2D-3D sketches and a 3D model. Secondly, the students were tasked to redesign their design studio considering the recent technological advancements on building design. In both tasks, the students were encouraged to ask questions, discuss with each other, and express their opinions and curiosities shall be prepared for the actual experiment.

4.2.2 Phase 02, Research

After the warm-up phase, all students were tasked to design a two-story single-house in a given parcel as the final assignment of the course (Figure 02, 03). Test group students developed their designs in parallel with the integration of BBC since the 10th week. Control group students also followed the same building design process, but BBC were given at the 13th week while they were at the 'stuff' level of the design process.

In the design studio, the author informed the students regarding the technical attributes of given BBC. Moreover, the students discussed their ideas of each other as in the natural atmosphere of the design studio. The students were neither given information nor guided on how the products can be integrated into the buildings, indeed, they were freed to choose not to integrate them at all.

Design Process of Test Group

The given design problem at the beginning of the design process to Test group was:

- To develop a design considering the role of the given BBC.

During the design process, particular integration stages experienced by the students were detected and categorized (Table II). Six (6) stages of integration determined; 'figuring out,' 'negligence' and 'rejection,' 'association,' and finally 'implementation.' The stages constituted by the systematic notes taken by the author in every class. The notes included both the verbal expressions and explanations regarding the draft drawings of the students.

Table II Integration Stages of Test Group Students

Stages	Explanation
Figuring out	More time needed to discover the technical attributes of the given BBC.
Rejection	Difficulty on the association of the given BBC with their design. Unlikely to negligence, the students argued that BBC were not related to architectural design.
Negligence	No verbal or visual indication of BBC in the student's design.
Exploring	Still searching the benefits of BBC for building design.
Association	The first pre-mature thoughts on connecting the given product with the other layers of the building.
Implementation	BBC started play role on architectural design.

These stages were not pursued by the students in order; each student followed a specific integration pattern by following and/or skipping particular stages (Table III). Almost all of the students except st02 needed time to figure out technical attributes of the given product at the beginning of the experiment. Later on, students pursued different paths.

Table III Followed stages of Test group students in the design process

	Week 10-T	Week 10-F	Week 11-T	Week 11-F	Week 12-T	Week 12-F	Week 13-T	Week 13-F	Final Design
st01	Figuring out	Rejection	Exploring			Rejection			Segregated
st02	Exploring	Association	Rejection	Implementation					Integrated
st03	Figuring out		Rejection	Negligence			Exploring	Implementation	Integrated
st04	Figuring out	Rejection	Negligence			Exploring		Implementation	Integrated
st05	Figuring out	Exploring	Association	Negligence					Integrated
st06	Figuring out	Exploring			Rejection		Exploring		Integrated
st07	Figuring out				Exploring		Association	Implementation	Integrated
st08	Figuring out	Rejection	Negligence	Exploring		Association	Implementation		Integrated

The expected result was that all students would reach the implementation stage in the design process, therefore BBC would be integrated in the final designs. However, the students st01, st05, st06 failed to integrate innovations into their designs during the process. St01 purposely rejected to design together with BBC after exploring the given innovation's technical attributes and benefits. St05 had trouble to associate the given BBC with building design therefore neglected the design problem, yet at the final design explained the impacts of BBC on 'space plan'. Likewise, st06 remained at exploring stage while the given period was not sufficient for him, even though he claimed that the given BBC was integrated into the building. Overall, all students except st01 reached the integration level in their final designs. Only st01 purposely rejected to integrate the given BBC.

Design Process of Control Group

Control group students followed the design process of the course until the end of the 13th week considering any example of BBC. Therefore they did not follow the integration stages, unlike Test group students. No difference between the two groups observed between the learning process and efforts regarding the issues related to architectural design.

In the 13th week, BBC were distributed to the students. In order to accelerate the figuring out stage, the students were helped by giving additional information; photos, websites, articles on the technical attributes of the given innovations. Moreover, as a natural advantage of the design studio, the students discussed the given examples with each other and tried to link them with their designs. In two (2) hours workload, the students assigned to develop their designs with the given BBC.

4.2.3 Final presentations & Key Results

In the final presentation, the students expressed their ideas verbally by explaining their drawings and/or models. The author also asked questions regarding the visual data which helped students to structuralize their approach and even encouraged to narrate more (Figure 04).

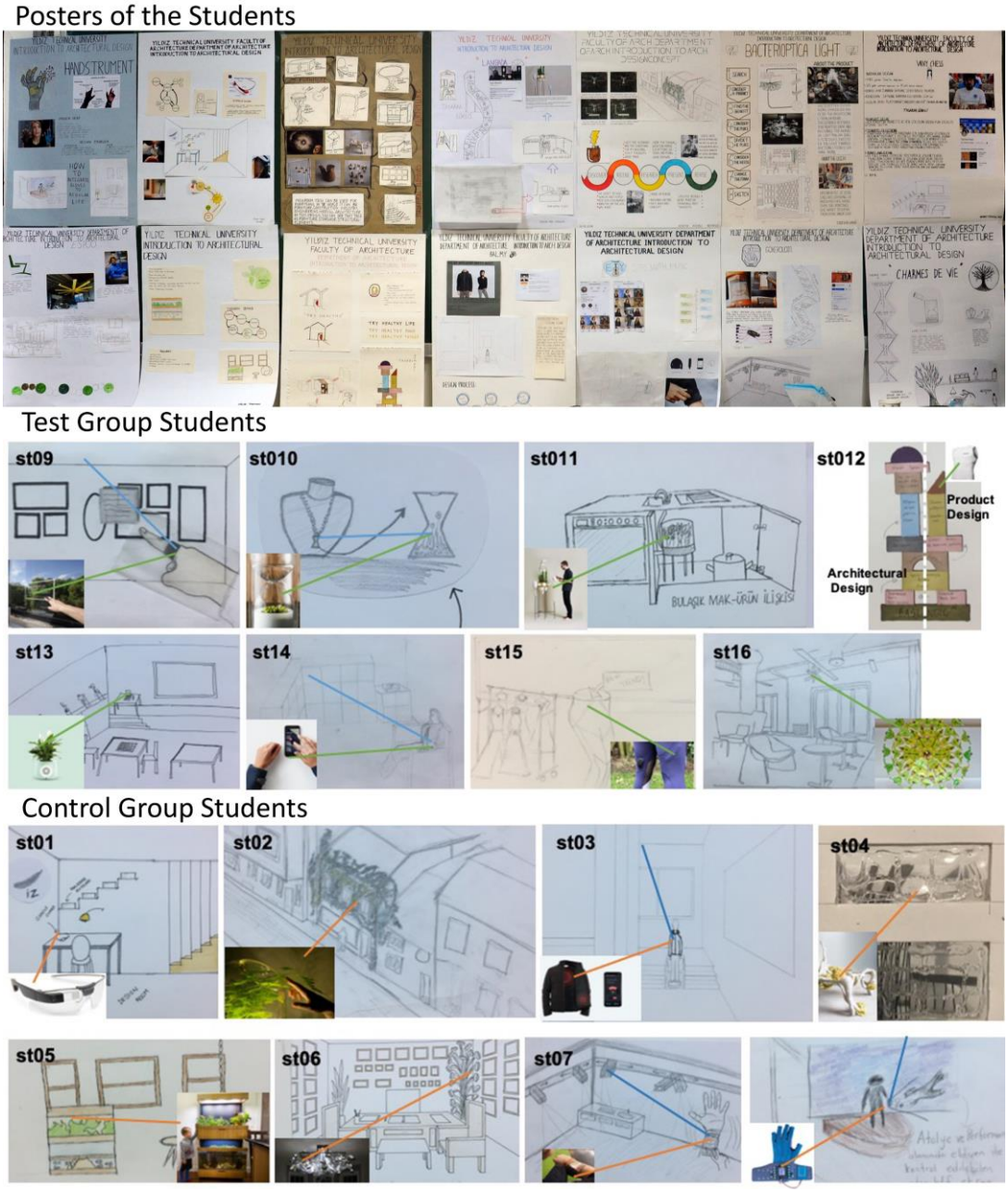

Figure 04 Final Presentation (the BBC shown by the author)

By following the steps of the PA method, the verbal expressions of the student presentations were encoded into information categories (Table IV). The main categories were identified as; '(affected) building layers,' 'approach,' 'advances' and 'prevailing concerns.'

Table IV Information Categories and Their Subclasses

Main Category	Subclasses	Examples of phrases in the protocols as evidence
Building Layers	Servant	'belonging', 'personal'
	Stuff	'furniture', 'portable', 'fitting'
	Space plan	'spatial', 'walls'
	Service	'HVAC systems', 'electricity'
	Skin	'façade', 'openings'
	Structure	'columns', 'beams', 'foundation'
Approach	Segregated	'architectural and product design cannot be united..'
	Integrated	'not a part of architectural design'
	Human-centered	'considering human', 'depending on human ..'
	Top-down	'started from site', 'space led people..'
Advances	Daily Activities	'everyday use', 'control' (the home environment),
	Well-being of Users	'psychological support', 'comfort'
	Sustainability	'organic', 'energy efficiency'
	Leisure	'hobby', 'fun'
Prevailing Concerns	Endurance	'estimated obsolescence rate', 'structural reliability'
	Economic	'affordability', 'expensive'
	Functional	'not required', insufficient'(features)
	Technical details	'lack of security', 'maintenance requirement'
	Contextual	'depends on site'

'Building Layers' led us to categorize the information on the affected building parts as a result of the integration of BBC. The 'approach' of the students was divided into four categories. Subclasses 'segregated' and 'integrated' implied the attitudes of the students towards product and architectural design in terms of accepting the impacts of BBC on building design. Subclasses 'human-centered' and 'top-down' appaired after the transcription of the data indicating the main concerns in the designs either centered around human or building parts hierarchically affecting the human. Moreover, 'advances' category indicated the benefits of the BBC stated by the students, whereas the 'prevailing concerns' verified the problems along with the prejudges.

While the presentations of the students were encoded into information categories, the tension between the conflicting answers became more apparent. The verbal expressions of the students and their sketches as shown in Figure 04 that was inconsistent for the both groups, but especially in Control group. Moreover, the differences between test and control groups became visible (Figure 05).

Figure 05 Encoded protocols of all students into information categories

Building Layers

Students in the test group integrated BBC into multiple building layers (Fig. 05). However, the students associated BBC with different building layers in their sketches, verbally they only mention one specific building layer. For instance, st3 had a vision regarding to buildings without mechanical systems, and the sketches tried to reveal the idea. Nevertheless, she only told the impacts on the service layer not on the entire building layers. In Control Group, students (st9, st10, st12, st13, st14, st15) could only relate the given innovations with stuff layer. St11 and st16 integrated the given examples into service layer, but only st16 mentioned the integration of BBC affecting other building layers.

Approach

The results on the approach of the students on the integration underlines the confliction between visual and verbal data (Figure 05). While five students (st2, st3, st4, st7, st8) in Test group advocated 'integrated' approach among product and building scale, only one student (st16) shared the same approach in the Control group. The students (st1, st5,st6, st9, st10, st11, st12, st13, st14, st15) declared that BBC is related to product design, and architectural design were segregated and they did not even affect each other. Nevertheless, in the drawings of (st9, st14, st16) the impact of BBC was apparent. The students (st1, st2, st4, st5, st6, st11, st12, st13, st14, st15, st16) argued that they proceed with a top-down approach. However, the subjects (st5, s6, st11, st12) also mentioned the impact of innovations on the well-being of human might advance the integration of technologies into the buildings. Likewise, the students (st9, st11, st12) underlined the benefits of the products on daily activities, but only st9 assumed their approach as human-centered.

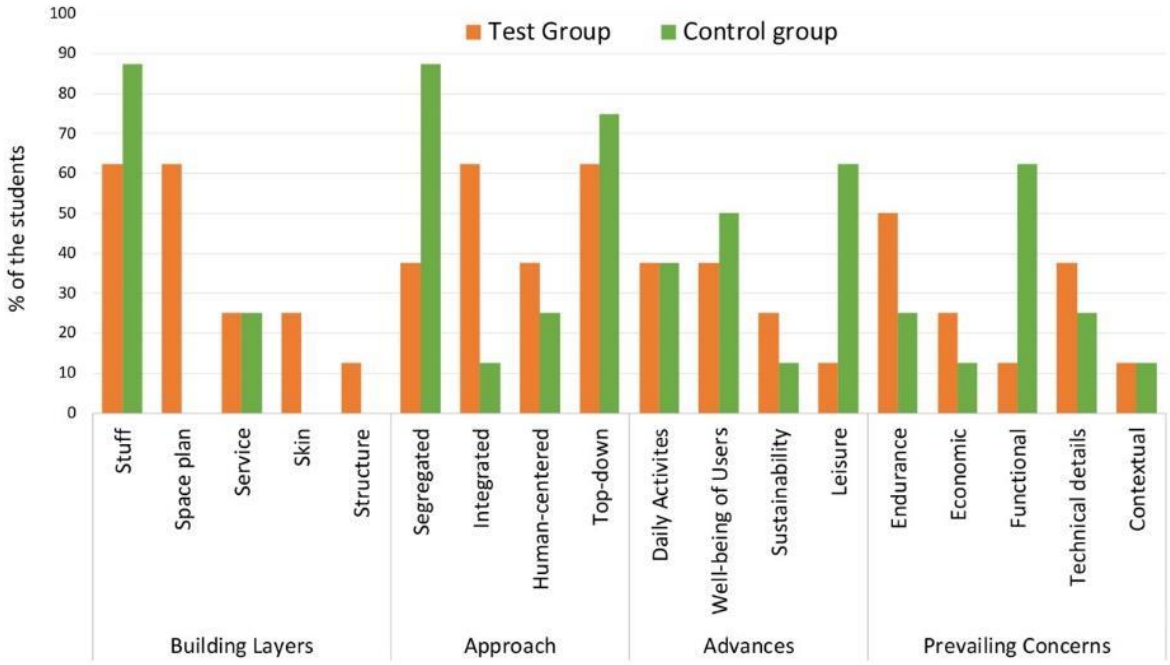

Figure 06 Comparison of the percentage of the students from the encoded protocols of Test and Control Group students

Advances
All of the students in both groups were aware of the advances of BBC. Test group students expressed these advances as one of their motivation on integration of the innovations. On contrary, Control group students (st9, st10, st13, st15) mentioned the benefits of BBC by being related to daily activities, well-being of users and leisure, but they foresaw these advances to unrelated with architectural design.

Prevailing Concerns
The prominent concern of Test group students was the 'endurance' of the products. Test Group students (st2, st4, st5, st6) highlighted the lack of knowledge on durability hampered the integration process. On the other hand, the major concern of Control group students was 'functional' by claiming that BBC were unnecessary and unrequired to be included into the buildings.

Finally, the design experiment underlined the infiltration of BBC into the building layers by observing the design process and analyzing both verbal and visual data. Designing with BBC from the beginning of the design process allowed Test group students to discover the potentials of the innovations in the entire building design process. Thus, BBC became an integral part of building design towards to attitude of the designer. On the other hand, the reports revealed that the introduction of innovations at the end of the design process intensified the concerns of the students on the functions and technical attributes of BBC. Control group students criticized innovations as being unnecessary and hard to use. They were also aware of the interaction between BBC and the other layers of the buildings as clearly seen in their sketches.

More importantly, the introduction of BBC at the beginning of the design process, led all students to develop their designs centered on humans, considering the interactions between user, product and the building. Introduction of BBC led Test group students to

develop their designs by creating bonds between human, product (BBC), and building in the entire building process. In contrast, control group students did not consider the relationships between user, product and architectural design unlike Test group students, their approaches mainly shaped around the followed top-down design process in which human affected by building design. Proceeding a top-down design approach and including BBC at the stage of stuff cause this confliction to consider them only as products.

5. CONCLUSIONS

This article contributes to the existing studies by underlining the innovations at the intersection of living and manufactured by entitling them as BBC, and then experimenting their roles on building design. The envision of this research is to highlight the idea that the boundaries between living and manufactured, natural and artificial is fading. The experiment indicates that BBC can be integrated into building design, while their introductions at the early stages of the design process increases their integrability. Therefore, BBC should be considered in the discipline of architecture at the earliest stages of the design education, along with the following remarks on the below.

The potential impact of BBC on building design

Due to its heterogeneity and complexity, technologies at varying scales blends in architectural design. From the urban scale to human scale, different layers of the buildings have been integrated with many technologies. Among them, smart technologies have infiltrated into the buildings with interactive products that enhance the quality of life. Thus, the ubiquity of technology has drawn an endless experience to daily lives, while buildings have changed in parallel with the accelerated technological evolution. In the meantime, arising materials and techniques have made it possible to create 'living' and 'growing' designs with the incorporation of living and manufactured components. Thus, architects has often challenged to design both 'natural' and 'technological' buildings.

The multi-perceptivity in the terminology

The overwhelmed number of terms referring on the studies at the intersection of nature and technology hampers to understand the novelty of studies and designs incorporating with the living organisms. The diversity in the terminology implies both a problem and a potential. The variety of terms point out the multi-perceptivity, extensiveness, and also the interest of academia and society on the researched issue. On the other hand, the lack of blanket term decreases the understandability of the studies. Likewise, the term of biobuilding components determines the focus of this study very clearly but makes difficult to comprehend the research at first. Since the term itself is not widespread, and can be misinterpreted.

Changing roles of the architects

Even though material scientist and product designers develop these innovations, and engineers and programmers write the code, architects have responsibility on integrating them into building design. Therefore, their approach to these technologies majorly influences our surroundings as well as our daily lives. The changes in the daily activities and everyday life through BBC and their increasing integration into the home environment will assumedly affect building design, thereby the roles of the architects will also be altered. Thus, the mindset of the architects needs to be revised with the growing number of innovations empowering the interactions between the user and the building.

Further studies

Conducting a design experiment that describes a multidisciplinary area of rapid growth, such as the introduction of BBC in the discipline of architecture, is challenging, yet promising. To deliberate this issue, further design experiments require especially with different actors as such urban designers and professional architects. Correlating the experiments with urban scale may also bring different results. To experiment by giving the

same innovations to each actor may also lead us to find results on the relationship between the technical attributes of the innovations and different ways of integration of the technologies into the buildings through their specific advantages on building design.

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