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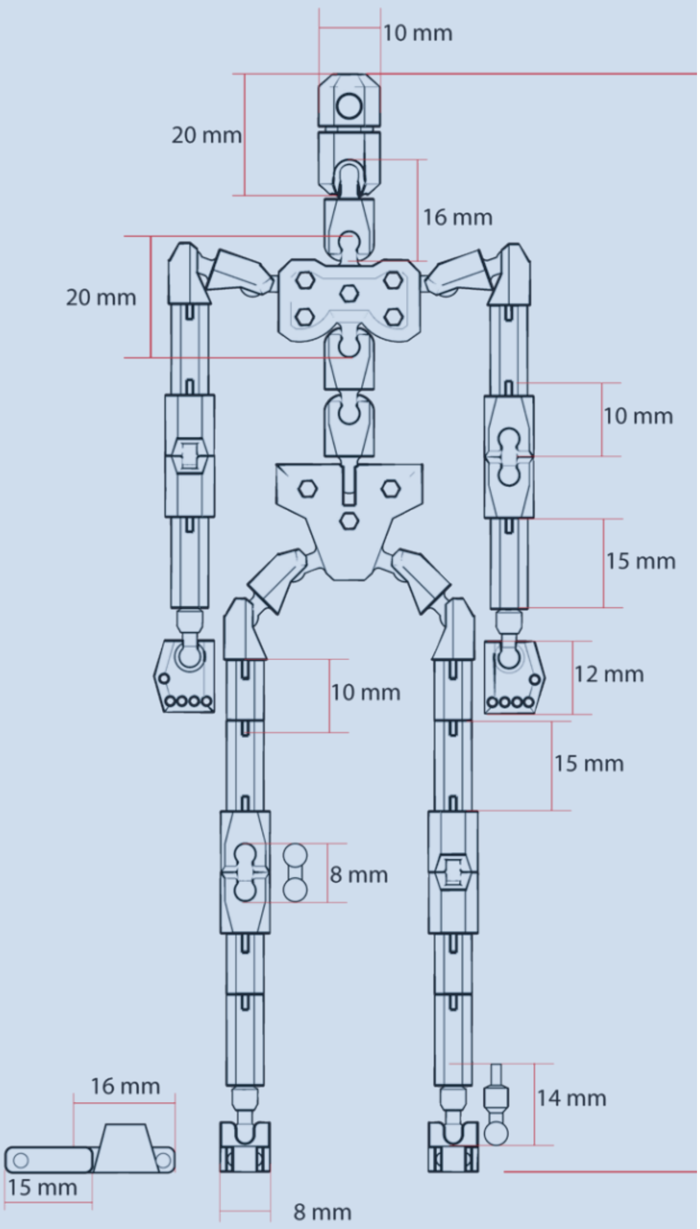

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Contents

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Product design activity as a process to develop a therapeutic toys for self-managed depression among adolescents

ABSTRACT

Adolescent mental health issues are on the rise, with rates rising from one in ten in 2011 to one in five in 2016. This issue was predicted to be one of the top causes of global disability by 2020. Hence, with the aim to develop a therapeutic toy for self-managed depression, this paper intends to elucidate the product design process based on the criteria of therapies practiced by patients to manage mild and moderate depression. Semi-structured interviews were conducted with a clinical psychologist, three licensed counsellors, and six young depressive disorder patients as a methodology for gathering empirical data, which was then followed by the design process. The result of the interview indicates a multitude of design needs in self-managed depression. Therefore, a few design criteria have been proposed and a set of the non-working models of the therapeutic toys was successfully developed as a proposal for potential future development and production. It is hoped that the outcome of the study exhibits the synchronization of the design thinking process inside the ergonomics ergo system framework in order to generate the design for the patient.

KEY WORDS
Depressive disorder, product design, adolescents, therapeutic toys, psychology

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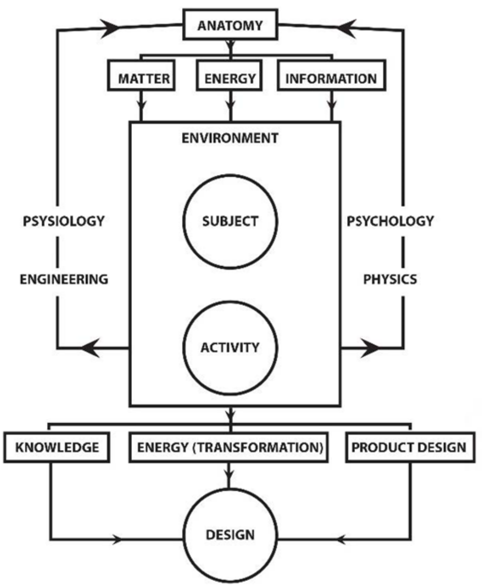
Introduction

According to a prior survey, mental health problems have grown from 10.7% in 1996 to 29.2% in 2015. For example, it is estimated that around 2.3 million Malaysians would suffer from mental illness at some time in their life (Mukhtar & Oei, 2011). There is a concerning trend with mental health disorders among adolescents, with estimates growing from one in ten persons in 2011 to one in five in 2016. According to Mustaffa et al. (2014), adolescents are afflicted by a variety of problems and components as they move from infancy to maturity, which operate as agents of change, impacting them inside and out and eventually shaping their behaviours and manners. Landback et al. (2009) indicates that twenty-five percent of all adolescents struggle with individual identity conflicts inside themselves and in society, which can lead to a depressive episode. As indicates by Mukhtar & Oei (2011), by 2020, depression as an emotional disorder will be one of the primary causes of global disability. It is thus critical to implement a preventative program, as well as early identification and treatment consultation.

This paper is a product design research article that looks at depressive disorders among adolescents. The primary objective of this research is to elucidate the product design process based on the criteria of therapies practiced by patients to manage mild and moderate depression and develop a therapeutic toy for self-managed depression. The ergonomics ergo system framework was used as a template for optimizing the system's operations in order to construct the therapeutic toys in this study. This framework was adopted from the structural ergonomics view of work system by Bridger (2008), adapted by Sani et al. (2020) and Kamil et al. (2020). As argued by Bridger (2008), the framework is made up of groups of components that interact with one another and the environment's factors. The framework's base is the synchronization of "people" and "machine" interactions to create a function toward developing and creating some type of output. The input from auxiliary factors such as matter, design requirements, and information differs depending on the level of human factors study. The framework is most commonly used as a template for optimizing system functioning, but it may also be utilized in the context of product design. The framework is formulated as a design model in this study to aid designers' design thinking from the early stages of empathically experiencing the case under investigation, brainstorming and coming up with a solution for the user's need (based on the insights gained during the empathizing stage), conceptualizing, and periodically testing the design prototype. The following five sets of ergonomics science elements speed up the system: (1) physics; (2) psychology; (3) anatomy; (4) physiology; and (5) engineering. The subject's synchronization in a certain environment is built into the system's basis. To make sense of the relationship, one must first comprehend the subject's state or situation (matter) while doing activities in a certain context or place. Theoretically, the condition or situation will provide information about the subject's reflection on the physics of the environment they are in, including how it impacts their psychology and needs. Nevertheless, the articulation of anatomy and physiological requirements will give much-needed design knowledge that may be improved further.



» **Figure 1:** *The ergonomics ergo-system framework, adopted from Bridger (2008), Sani et al. (2020), and Kamil et al. (2020)*

The study uses the Design Thinking approach to spotlight the increased psychological comfort of the toolkit's user by synchronizing the use of ergonomics ergo system framework with other elements that are taken into account, such as human psychology and engineering. The explanation provided in relation to Ergonomics and Design Thinking relevancies, as well as the demonstration of the product design process, aims to broaden the scope of knowledge, leading to more design research exploration based on the integration of cross-disciplinary studies with psychology relevancy.

Methodology

The design development process was steered by the foundation set by Verduyn (2000), Saravanan, Alias & Mohamad (2017), and Sinniah et al. (2017) who investigated the effectiveness of individual cognitive behaviour therapy in depression. Their research, that is also in accord with numerous research such as treatment approaches for reducing the risk of major depression in adolescence including group cognitive-behavioural and individual interpersonal psychotherapy (Landback et al., 2009), tactile therapy as an effective psychological comfort (Schmidt, 2006; Kamil and Abidin, 2013; Fritz and Fritz, 2020), recovery rates in major depressive disorder patients (Novick et al., 2017), study of shape, colour and lights as a therapy for depression (Wileman et al., 2001; Loving et al., 2005; Kim and Kang, 2013; Roseman-Halsband, 2018; Hajra and Saleem, 2021), finds that the integration of tactile sensory, colours and design elements in cognitive behaviour therapy have significant potential to elevate comfort among adolescent with depressive disorder. This data plays an important element for the development of therapy product for adolescents with depressive disorder.

In this study, the development of therapeutic toys aims to meet the needs of adolescents suffering from depression (hereinafter referred to as patient) and to improve their psychological comfort. In order to assess design requirements needed by patients, including the optimal design function to be applied in the therapeutic toys, therefore, an assessment through semi-structured interview study was conducted with a clinical psychologist, three certified counsellors, and six patients. The interview session was conducted within 45 minutes per sessions at Clinical Psychologist Borneo Medical Centre, Sarawak, Malaysian Mental Health Association (MMHA), Selangor, and Universiti Sains Malaysia (USM), Penang. The context of interview was specifically designed based on the five sets of ergonomics science elements as proposed in the ergonomics ergo system framework (physiology, psychology, physics, anatomy, and engineering). For instance, the interview session with the clinical psychologist was designed to obtain a professional opinion regarding depressive disorder such as symptoms and diagnosis of depression (psychology), the impact of the untreated depressive disorder to physical well-being (anatomy and physiology), and medical treatment available for depressive disorder. Meanwhile, the interview session with certified counsellors was designed to obtain a deeper understanding regarding the toolkits therapy technology (engineering) and variation of CBT approaches such shape, colour, lights, and tactile therapy (physics). On the other hand, the interview session with patients was designed to assess design requirements needed based on their psychological response towards the existing CBT including the shape, colour, lights, and tactile therapy (psychology and physics).

Data analysis and result

Phase 1: Assessing the design needs

The analysis of the interview was part of the phase in design development process that involves synchronizing the ergonomics ergo system framework and the design thinking process to inform a clear design direction. During Phase 1, the data from interviews were analysed to gain an empathetic understanding of the respondents, the therapy and intervention, and design needs. Adopted from Perreault (2009) and Saldaña (2009), the written verbal transcriptions from the interview data were analysed and systematically categorized into information categories using three phases of coding: (1) open coding; (2) axial coding; and (3) selective coding. For example, in a study of respondents' perceptions of colour variations in therapy (see Table 1), the researcher categorised the selected emphases of the respondent's utterance and retrieved the utterance's characteristics. In this work, open coding begins with the creation of simple descriptive labels or characteristics of speech analysis. An excerpt of open code from one of those utterance analyses may be seen in the 'Open Codes' column.

The open codes are then organised into axial codes, which are more abstract conceptual categories. Selective coding, in particular, entailed sorting and relabelling comparable coded data reduced from open codes into conceptual groups. The code is refined during the cycle to get the optimum match, and more than one axial code

Table 1

Sample of coding on respondents' perceptions of colour variations in therapy (open codes)

Respondents' Index	Protocol Time	Transcription	Attributes	Open Codes
Respondent 1	15:30	*"...I will feel more comfortable if I manage to walk around in a jungle nearby my house ... enjoying the green, yellow...earth colour palette of the nature."*	1. Enjoying the forest and nature will make respondent feel more at ease. 2. Green, yellow, earth colour palette	The green, yellow, and earth colour scheme of the jungle and nature make the respondent feels more at ease
Respondent 2	25:15	*"It always seems to me that the white sandy beach and blue ocean will comfort me for a time being..."*	1. Enjoying the ocean and beaches make respondent feel more at ease. 2. White, blue colour	The white and blue colour scheme of the ocean and beaches make the respondent feels more at ease.
Respondent 3	18:55	*"I love the colour on my cat fur. It is kind of pastel grey... rubbing it for some times helps me to feel calmer."*	1. Rubbing cat fur make respondent feel more at ease. 2. Grey, pastel colour	Rubbing the grey and pastel colour of the cat fur make the respondent feels more at ease.

Table 2

Sample of coding on respondents' perceptions of colour variations in therapy (axial codes).

Respondents' Index	Protocol Time	Open Codes: Categories of information	Axial Codes
Respondent 1	15:30	The green, yellow, and earth colour scheme of the jungle and nature make the respondent feels more at ease	The colour of nature such as green, yellow, and earth colour scheme help in therapy
Respondent 2	25:15	The white and blue colour scheme of the ocean and beaches make the respondent feels more at ease.	The colour of nature such as white and blue help in therapy
Respondent 3	18:55	Rubbing the grey and pastel colour of the cat fur make the respondent feels more at ease.	The colour of living nature such as grey and pastel colour help in therapy

might be produced throughout this process. Furthermore, information that was 'split' or 'fractured' throughout the open coding process will be carefully reassembled. The axis is a category derived from open coding at this level. A 'dimension' is a phrase used to describe a category, and one of the goals of early coding is to find these dimensions and arrange the available codes along them. For example, the open codes introduced in Table 1 have been renamed and reorganised in relation to one another (see Table 2). After determining a category or dimension, the researcher may need to go back to the data and recode the data in relation to the emergent notion summarised in the category or dimension.

According to Muller and Kogan (2012), selecting which codes (from the axial codes) to develop further required a decision on what themes to study. The information was derived through selective coding by analysing the interrelationships that arise among the categories created in axial coding (Perreault, 2009). In order to produce explicit information, the selected coding maintains only relevant and applicable variables to the core variables during the process. The core category (axial coding) was stated as an information statement, which was then categorise and recoded as selective codes (see Table 3). To establish the link between codes and achieve the most credible theory, this procedure may need to be repeated a few times.

Theoretically, adapted based on the ergonomics ergo system framework, the analysis of interview data (through coding process) in this study is an early stage of empathically experiencing the case under investigation; assessing design requirements needed by depression patients among adolescents in the context of five sets ergonomics science elements that interact with one another (physiology, psychology, physics, anatomy, and engineering). Throughout the analysis of the interview, the information of condition or situation of depressive disorder was provided based on respondents' reflection on the situation and environment, including how it impacts the psychology and needs of patients. Nevertheless, the understanding of the anatomy's articulation and physiological requirements through the interview study help to determine the optimal design function and design knowledge that may be improved further in the therapeutic toys design process. As a result, the outcomes of the interview study were summarized in six elements of solutions (see Table 4)

Table 4

The description six elements of solutions

Elements of solutions	Descriptions
Self-image	The therapeutic toys should be able to boost patient's confident level to realize their strength and abilities
Emotion management	The therapeutic toys should be able to boost patient's confident level to realize their strength and abilities.
Self-regulating	The therapeutic toys should be able to provide the feel of comfort, secure and calmness.
Assistive toolkit	The therapeutic toys should be assistive to reduce sensory dullness, stress, and anxiety.
Assistive in expressing	The therapeutic toys should be assistive to help the patient manifest their inner trauma and promoting positive interaction.
Cognitive comfort	The therapeutic toys should be able to elevate positive cognitive thinking and behavioural tendency.

Phase 2: Generating design ideations

Previously in Phase 1, the six elements of solutions were generated through the result of interview analysis and synthesis. Meanwhile in Phase 2, the six elements of solutions help in brainstorming process to generate the design criteria of the therapeutic toys (see Table 5).

Based on the outlined design criteria, the therapeutic toys will include a form inspired from organic shape and

Table 3

Sample of coding on respondents' perceptions of colour variations in therapy (selective codes)

Respondents' Index	Protocol Time	Open Codes: Categories of information	Axial Codes	Selective Codes
Respondent 1	15:30	The green, yellow, and earth colour scheme of the jungle and nature make the respondent feels more at ease	The colour of nature such as green, yellow, and earth colour scheme help in therapy	The colour inspired by nature such as green, yellow, white, blue, grey, pastel and earth colour make the respondent feels more at ease during therapy
Respondent 2	25:15	The white and blue colour scheme of the ocean and beaches make the respondent feels more at ease.	The colour of nature such as white and blue help in therapy	
Respondent 3	18:55	Rubbing the grey and pastel colour of the cat fur make the respondent feels more at ease.	The colour of living nature such as grey and pastel colour help in therapy	

biomimicry. It is hoped to help reducing sensory dullness by manipulating the soft tissue, neuroendocrine system, connective tissue system, and circulatory system. Furthermore, the implementation of form inspired by biomimicry design (inspired animal) is hoped to elevating users' positive thoughts and emotion through natural elements. In order to enhance the aesthetic elements of the design, a sleek natural element with calming colour will be embedded. The calming colour mixing also will be used as therapy to emotionally react to the visual brain and cause psychological phenomena. The design also will be implemented with playfulness elements such as squeezable and bounceable, through the physical form of the design. The interaction between the physical form of the design and user will help to provide a fun interactivity and eliminate negative thoughts. Finally, we have also suggested that a low-cost, nimbler, and safer material such as three-dimensional (3D) printed plastic Acrylonitrile Butadiene Styrene (ABS) and silicon to be used for design production.

Table 5

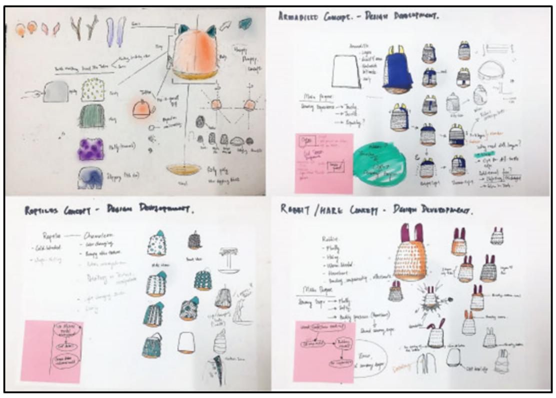
The description of design criteria

Design Criteria	Descriptions
Tactile sensory experience	Aim to help reducing sensory dullness
	Manipulates the soft tissue, neuroendocrine system, connective tissue system, and circulatory system
	The design form inspired by organic shape and biomimicry design.
Aesthetic	Using calming colour for the design
	The design form inspired by nature
	Sleek design
Mixed material	Using low-cost, nimbler, and safer material such as three-dimensional (3D) printed plastic Acrylonitrile Butadiene Styrene (ABS) and silicon.
Colour mix and match	Colour will be used as therapy to emotionally react to the visual brain and cause psychological phenomena.
	Calming colour mixing
Emotional design	Aim to help elevating users' positive thoughts through nature elements
	The design form inspired by animal (biomimicry design)
Playfulness	Aims to eliminate the negative thoughts through fun interactivity
	Playful physical interaction between user and product

The mood board design concept was first executed in Phase 2. The mood board is a visual guideline that was created based on the design criteria (Kamil & Sani, 2021). The visual guideline used in this study was developed from a variety of sources, including natural forms and shapes, colours, and physical properties. These visual guidelines aid the research team in determining the appropriate design direction as indicated by respondents in the interview study. The forms and shapes of rabbit and hedgehog, for example, influenced the visual characteristic of therapeutic toys while the pastel colours and earth colour palette influenced the colour variation. The physical qualities of natural elements such as fur, spikes, and tentacles will, however, influenced the textural properties of the design (as part of element in tactile therapy).

» **Figure 2:** *Design concept mood board*

The design ideation process was carried out using a sketching activity based on the mood board design concept.



» **Figure 3:** *Design ideations development*

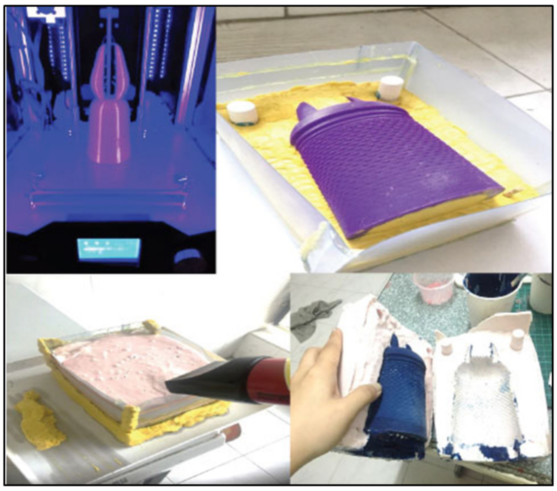
Sketching activity help to better understand the visual composition and structure of form design, functionality of form aesthetics and format of form ingredients (Kamil & Abidin, 2015). Throughout the process, the therapeutic toys' visual shape was developed in accordance with components generated from design criteria and visual guidelines in the mood board design concept.

At the end of Phase 2, the outcome from the sketching activity was generated into three-dimensional (3D) design using Autodesk Inventor 3D Design software. During the process, the dimension and visual appearance of the design was enhanced realistically. The outcome of the 3D design helps to obtain a proper understanding of the therapeutic toys such as the textures, colours, and product proportions.

» **Figure 4:** *3D design*

Phase 3: Model making process

During Phase 3, the model making process were executed. Making a model helps designers to see how the product tangible looks in, and to ensure that a product is viable. This involved three-dimensional printing process (based on 3D files generated in Phase 2), moulding process using silicone mould, and product furnishing. Throughout the process, the technical aspects of the model were investigated on a regular basis to ensure that all design flaws were addressed. At the end of this stage, a preliminary grasp of the restrictions inherent to the therapeutic toys, as well as how real users would behave, think, and feel when handling the product, was gained.



» **Figure 5:** *Model making process*

The final non-working model is eventually completed, established, and validated after the serial iteration phases, which entail several adjustments to match the proper comfort of the user. The main features validating the non-working model are the characteristics of aesthetic involving the current therapeutic toys' design style or fashion, as well as the technological consideration emphasizing how real users would behave, think, and feel when handling the end product.

» **Figure 6:** *The final non-working model*

Discussion

The product design process has proven the possibility of integrating the theoretical study with the product design context. Based on the study, our research team proposes The Moody Lab, a trio set of three roly-poly therapeutic toys for self-managed depression among adolescents. The Moody Lab therapeutic toys aims to provide a calming effect on emotion management for adolescent with depressive disorder by reducing symptoms and managing emotions such as sensory dullness and lose concentration through an understanding of theoretical and interview study, design thinking process, and alignment with the outlined design criteria. The element of tactile sensory experience implemented in the design was inspired by organic shape, peaceful colour mixing, and biomimicry design, all of which will be used to enhance tactics in the therapeutic toys. The element of organic tactile body parts that can be squeezed in the design will helps to manipulates the soft tissue, neuroendocrine system, connective tissue system, and circulatory system, which also helps to lower cortisol stress hormone levels. As a result, it will decrease the psychological effects of stress, anxiety, and sadness. Nonetheless, the element of biomimicry design in bodily parts (using animals as examples) will serve to emotionally affect users' positive thoughts, perceptions, and provide a sense of playfulness. Relaxing colour variation implemented in the design will be used as a therapy to emotionally react to the visual brain and cause psychological phenomena. The user's feelings and senses will be influenced by differences in brightness, saturation, and colour coordination.

» **Figure 7:** *The Moody Lab therapeutic toys*

Conclusion

This research has successfully developed The Moody Lab therapeutic toys as its design proposal to be used during cognitive behavioural therapy intervention and helps to elevate patient's psychological comfort. During the process, ergonomic comfort characteristics such as (1) cognitive comfort, (2) playfulness and (3) psychological comfort, are significant to the construction of therapeutic toys. By allowing users to discharge their negative inner thoughts, it aids in the elimination of negative beliefs about oneself. This relevance has been primarily created by the aesthetic design, the fusion of materials in product creation, and the ergonomics criterion. Furthermore, because users are considered essential stakeholders in design practice, the synchronization of the empathetic protocol in the Design Thinking research process highlights the relevance of user feedback. In this case, the issue addressed by the user helps to determines the function of the developed design. The six solution and design criteria elements have properly described the user's requirement for depression management. The proposed therapeutic toys have the potential to be further developed and mass-produced. This may be accomplished by implementing the design criteria's suggested elements. With this advancement, it is envisaged that the product can aid depressive disorder sufferers, especially among adolescents. However, in order to further evaluate the applicability of the proposed therapeutic toys, a comprehensive user testing and assessment of the product's effectiveness is necessary in the near future.

Acknowledgement

The Moody Lab therapeutic toys copyright number: AR2018005129 is patented under the ownership of Universiti Sains Malaysia.

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Parametric architectural design using shapes and structures

ABSTRACT

This paper explores the creation of architectural structures through parametric design tools. The proposed methodology presents an alternative framework of using digital tools for the product design development from the design thinking point of view. The main core of the suggested design process includes a great number of theoretical issues from design identity, design language and architectural design areas. As a result, designers can develop constructions for public spaces that are based on innovative morphologies by using new digital design techniques such as computational design (Rhino3D© and Grasshopper©). The development of an architectural structure that aims to bring greenery into the city and increase the rest and action spaces is presented. A valuable aspect of this exploration is in positioning the proposed design framework inside - to aid in the creative process and better leverage downstream outcomes. The final steps of the proposed methodology include the production of the final architectural structure through rapid prototyping, laser cutting and engraving techniques.

KEY WORDS
Design thinking, design language, computational design, design development, architectural structures, prototyping

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Introduction

Sketching is the essential language of architecture and product design. Design language is used to express concepts through simple planar or spatial entities, correlated to forms generated by geometric thought (Rossi, 2006). In the sequence of cognition, shapes are the one that the human brain acknowledges and remembers. Therefore, the product shape portrays product identity and gives significant impact to its user/customer's perspectives (i.e., brand connection, emotional experience, consumer needs) (Wheeler, 2003). Design thinking process implicates the ability to synthesize inspiration from variety of sources (e.g., mind-map, mood-board, empathy maps, persona, etc.). Design thinking methodology is a unique tool in a holistic product design (Manavis & Kyratsis, 2021). On the other hand, Conceptual Product Design approach is perceived mainly as an art than an actual science. The main theme of Conceptual Product Design methodology is based on the design thinking principles: empathize, define, ideate, prototype and test (Manavis et al., 2020). Architecture has always embraced innovative ideas, materials, and techniques. Contemporary architecture and product design are no exception (Caetano & Leitão, 2019). Architectural design is essentially characterized as a collective process that unifies a great number of different professions. Architectural and product design make necessary the collaboration between designers, engineers, and technicians (Herr et al., 2011). Furthermore, the new role of architecture requires the creation of innovative shapes- from the geometry point of view (Casale et al., 2013) and at the same time – it is important to refresh the creative process towards the development of architectural forms. This is true and it is achieved by using the possibilities of new digital tools i.e., computational design (Oxman, 2017) and enhance communication between architects and potential users (Ņitavska & Mengots, 2018). The present article combines two different design approaches. Specifically, the ideation sketches and prototypes from the designer's sketchbook in correlation with advanced digital techniques of parametric design. The core reason of this experimentation from authors point of view is about the development of innovative and unique architectural structures.

Parametric modelling in architecture

Parametric design or modelling is a method applied in various areas and has gained an important role even in architecture. The digital model is created automatically based on a series of computer-generated rules. Digital technologies perform a crucial task, to translate the architect's idea through virtual spatial models. Bearing in mind that through FEA analysis models or systems can be evaluated in a virtual environment in order to fix various issues occurring during simulation, thus raising the performance of the virtual model, their role is determinant in increasing accuracy, reducing time and increasing productivity. Moreover, by using FEA analysis, avoiding any failure that might occur with the physical model. Since architecture is constantly looking for innovative ideas, new techniques, and materials-designers are increasingly using methodologies of computational design and digital production. Computational design endeavours to quantify the desired properties, characteristics, and behaviours of a building organism, which may be considered as a system – structured set of spaces and building components designed to satisfy certain goals (Fioravanti, Loffreda & Trento, 2011). In addition, through parametric design, it is easier to calculate and form a basic shape in variable structures, even if its geometry is strange and indeterminate. Use parametric strategies results successful for designing interactive motion facades (Panya, Kim & Choo, 2020) and is effective in combination of form parameters with various assessment tools in different analysis (Suyoto, Indraprashta & Purbo, 2015). Moreover, the combination of parametric methods for designing with optimization algorithms can be used to solve various design problems in architecture (Liang & Wenshun, 2019).

There are different possibilities and approaches of parametric modelling, which are adapted by artists and architects in the realm of urban art. As a result, they bring new possibilities and future directions of parametric modelling in both fields of architectural design and urban art (Leung, 2019). Inspirations from nature combined with computational modelling display a great importance in the reflection of biomimesis on architecture, and that this multi-dimensional and multi-disciplinary concept could be transferred to another discourse – architecture –accurately and efficiently (Sorguç & Selçuk, 2013). Due to a rapid development occurring in technology, makes it necessary to respond these changes by introducing them in educational level, in order to offer students new skills acquired. As a result, introduction of parametric modelling at educational level presents advantages in enabling conversation among students (Symeonidou, 2019), between disciplines (Woodbury, Williamson & Beesley, 2011; Jancart & Stals, 2019), and creating a digital continuum from concept to physical object (Gallas et al., 2015; Agirbas, 2018).

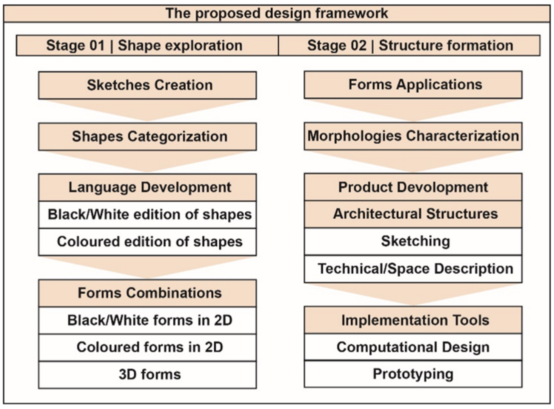
Digital manufacturing in architecture

Creating prototypes is the first step of architects. These prototypes are further used to evaluate them aesthetically, structurally, etc. The widespread use of rapid prototyping techniques (RP) or 3D printing in architecture modelling seems to have an important role. 3D printing technologies are easy, rapid, and economic to create and build models. It can serve in the field of architecture by replacing traditional modelling methods (Gibson, Kvan & Wai Ming, 2002), (Bayar & Aziz, 2018). These applications are present including kinetic architecture as well (Ferschin, Di Angelo & Brunner, 2015). As one of the advantages of 3D printing is production of complex geometries which can be parametrically controlled results in creating architectural structures for landscapes (Bañón & Raspall, 2020). 3D printing also results useful to have a better view of the design idea (Howeidy & Arafat, 2017) and by reducing material wastage resulting as a great advantage for sustainability (Beyhan & Selçuk, 2017). Projects created and implemented by various researchers results in an effective application of 3D printing in architecture (Raspall & Bañón, 2018).

An example application of the three-dimensional representation is the urban design, whose morphology and layout are studied, determining the character of the city (Bonivento et al., 2011). Projects developed using subtractive and additive manufacturing systems, together with robotic process are necessary to produce object difficult to be produced using conventional processes, this due to their irregular geometry (Sousa, 2017). A particular urban element that can take many forms in design is the square, where through 3D illustrations it allows designers to provide the optimal solution (Charlton, Giddings & Horne, 2008) so as to achieve the upgrading of these public open spaces, offering comfort and indulgence to both the inhabitants of the city and its visitors, (Pezzica, Lopes & Paio, 2016) considering the design and cultural heritage of each area. Reflecting therefore the overall image of the city and through the implementation of various activities, the arts are highlighted along with cultural activities. At the same time, it is important in these spaces to achieve through social inclusion and communication between people (Dormidontova & Belkin, 2020). Finally, understanding the importance of the squares, it becomes necessary to design and build more urban spaces, which reflect the modern image of society.

Design methodology

According to the following design process (Figure 1) any designer can follow the proposed methodology in order to create a personal design language that can be used in the creative design context by using parametric tools. The framework is separated into two design phases.

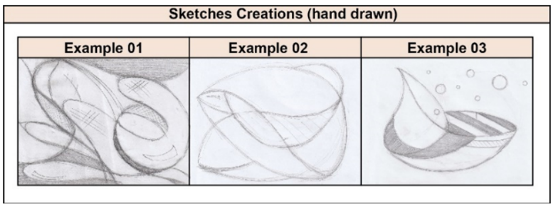


» **Figure 1:** *The proposed design framework*

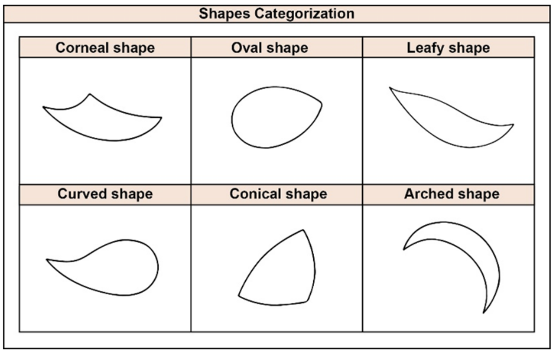
The first phase includes all the specific steps of creation of abstract sketches by hand. The classification of sketches includes two different approaches. The first categorization separates the drawings by the representation goal from the designer's point of view. Specifically, the basic types of the sketches are ideation, explorative, explanatory, and persuasive sketches (Manavis et al., 2020). The second taxonomy concerns the technical features of the sketches. Notably, a) the descriptive lines, which designers draw to convey the form of an object and the b) intermediate construction lines, which help designers draw the descriptive lines with accurate proportions and perspective (Gryaditskaya et al., 2019). The produced abstract designs from designer's point of view was categorized and grouped based on their repetitive patterns. These groups of abstract shapes develop a novel design language. The produced design language consists of individual elements (black/white and coloured editions), through which new combinations of abstract forms are formed. The designer himself is responsible for the creation and selection of these final combinations of forms. The second phase includes all the compositions, which were formed based on these evolving the reasoning process, creating new possible forms, through which the final proposal will be materialised. Furthermore, three-dimensional designs will emerge through the use of parametric programming and source code rules that are formed according to the commands, parameters, constraints, and options to be defined each time by the designer. Finally, it is presented an illustrative case study which includes architectural drawings, photorealistic illustrations, and a prototype model.

Stage 01, Shape exploration

A couple of designers created forty different abstract drawings inspired by nature formulas. The core concept of all these random sketches is about the designers couple unique sketching style (creator's artistic style). Figure 2 shows three different and representative examples (Figure 2). Creating a series of sketches with specific morphological details, a pattern of repetitive forms is developed, with the aim of a final series of individual elements- the letters of the proposed design language. The process of grouping these patterns was done with visual criteria. All the sketches were categorized into six specific and unique formations. Each shape is a primitive form with all these unique features: angles, curves, direction and weight(Figure 3). In particular, with the use of transparent layer of paper and through the search for each design, the patterns that made them up were isolated. In this way, large groups were created with common characteristics (such as cornea, oval, leafy, convex, conical, and arched). Through this process, new subgroups emerged, which would form the basis for further processing.

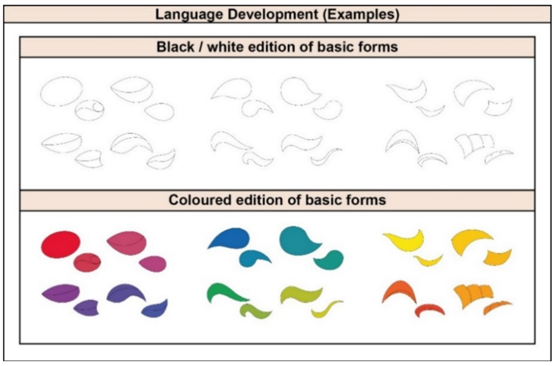


» **Figure 2:** *Sketches creations*

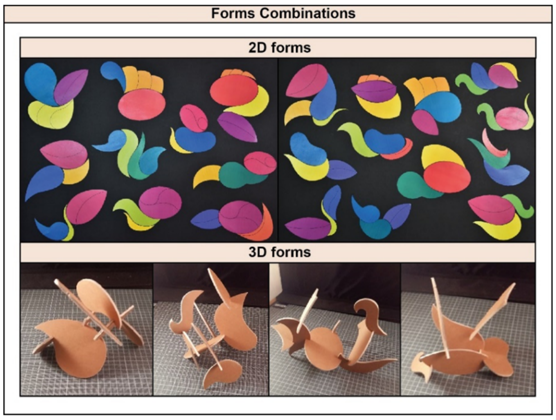


» **Figure 3:** *Shapes categorization*

Comparing the common patterns with each other, the resemblance and repetition of some of them is even more pronounced, with small design differences. The proposed language is consisting of a specific number of individual elements, representing the general identity of the designer. In this way, it is possible to compose new forms from the creation of specific pure forms. The proposed design language is composed of twenty-eight shapes. All shapes include two kind of morphologies – big shapes represent the upper-case letters of the design language and the small ones, the lower-case letters (Figure 4). The transition, modification, change in their form is done design smoothly, starting from a circular element and ending in an identical circular element. In order to give one more information and property to each individual element, the colouring of the linear elements based on the colour wheel was chosen. Starting with the red colour and the first element, a new specific colour was assigned to each shape gradually. The combinations of the shapes are up to designer's aesthetics criteria (Figure 5). All the new morphologies are created randomly according to designer's instinct about future structures that will be transformed into products and/or architectural applications. Designers created twenty-two different combinations of 2D shapes according to geometrical and connectivity criteria of each pair of shapes. Furthermore, the designers updated the two-dimensional shapes into 3D forms. Specifically, twenty different abstract 3D forms were created by the couple of the designers. Figure 5 shows three unique examples of forms. For the proposed 3D transformations designers kept the same criteria as a previous stage (geometry and connectivity). Finally, creators selected two different options of the twenty alternatives. In this paper only one structure is presented as a case study.The final proposal represents morphologies and structures from both 2D and 3D perspective. Finally, having created all the new two-dimensional and three-dimensional abstract forms, some benefits arose for the designer: the development of critique in terms of aesthetic perception, the acquisition of freedom in the formation of new compositions, the management of freedom in composition along with the constraints that arose, as well as the possibility of using this process as a new design methodology, with a wider range of ideas.



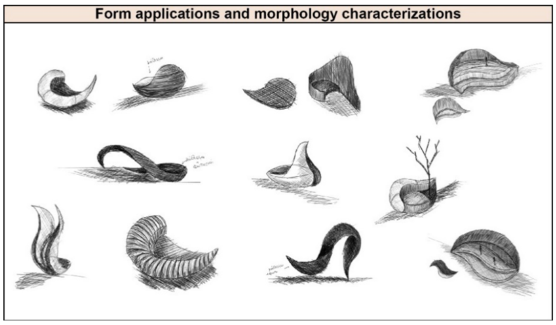
» **Figure 4:** *Examples of language initial forms*



» **Figure 5:** *Form combinations*

Stage 02, Structure formation

The proposed second stage of product design involves four critical substages (Figure 1). First stage is about discovering forms and structures from specific morphologies of applications point of view. This stage focuses to designer's creativity. Furthermore, in this stage designer uses a great number of inspiration tools (i.e., mind map, mood board, sketching, storyboard, and prototype) to explore and visualize the final concept of product. All inspiration tools were used as creative techniques in order to explore the range of different ideas and concepts (Manavis et al., 2020; Manavis & Kyratsis, 2021). Specifically, the mind-map was used for the idea exploration of the main concept (parametric architectural design using shapes and structures according to designers unique sketching style). On the other hand, the mood-board and the free-hand sketching are special tools and techniques for the holistic approach of design. First, the mood-board was used for the idea's visualisations and after that, free-hand sketching for the main concept representation.

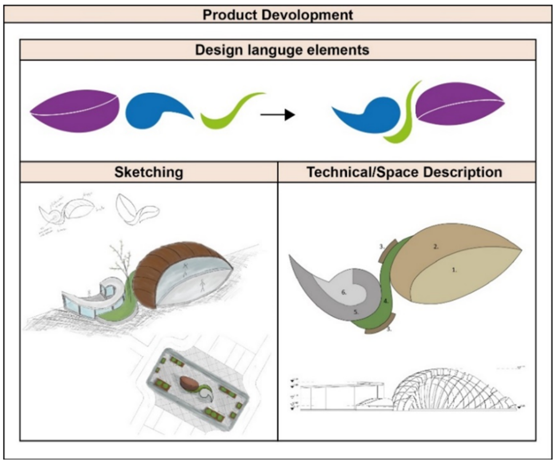


» **Figure 6:** *Form applications*

Finally, the tool of prototyping is a crucial step for the creation of the final concept forms as physical entities- the prototypes were crafted by paper. In structure development stage is presented a detailed architectural structure. The implementation tools area digital sketching software for first concept approach (Figure 6), a vector design application for the technical description of the structure- including the environment space (Figure 7), a parametric design tool for 3D digital modelling development (Rhino3D™ and Grasshopper™) and finally, a specific rendering tool for photorealistic images of the final structure (Kyratsis, 2020; Kyratsis, Kakoulis & Markopoulos, 2020).

Case study: Architectural structure

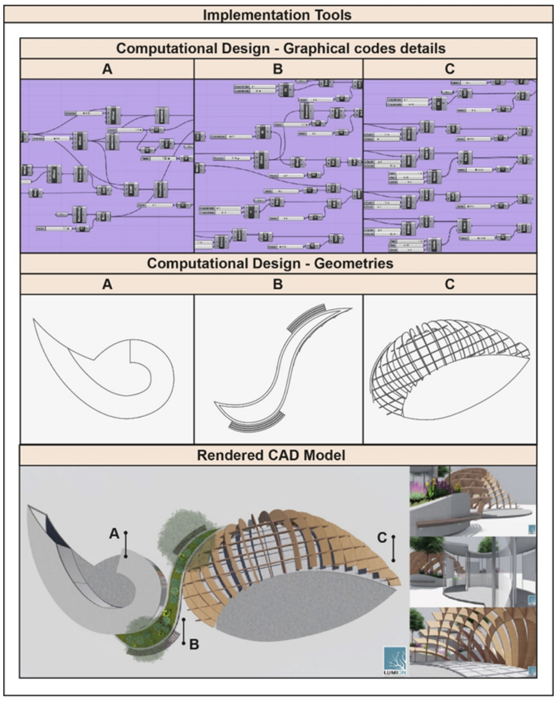
According to the previous design framework, the designers selected three different 2D shapes in order to build a three-dimensional structure. The criteria that were used fits with the geometrical features of each form and finally with the connectivity perception. Figure 7 shows the combination of the design language elements. Furthermore, Figure 7 notes the final sketching approach from the architecture structure. The architectural construction presented in this work with total maximum dimensions, of height 25,35m, width 12,00m and depth 4,90m is formed by the combination of three coloured shapes (Figure 7). The placement of the construction due to its shape is suitable for open elongated public spaces. The large construction on the right is the main platform for people's free movement or for an organization of a public event. The main base of this structure is made of cast material for the formation of curves, with a height of 0,15m and 0,10m above, of a different grey shade to stand out. The wooden construction is a modular connection between the curved wooden planks, thickness 0,04m - maximum construction height is about 4,90m (C).



» **Figure 7:** *Product development (1. Free space and podium, 2. Shell, 3. Rest point, 4. Greenery section, 5. Exhibition space and 6. Yard)*

The middle part of the architectural synthesis is served as a resting point, and it includes wooden benches and a green space through the trees and flowers into a curved shape (B). In addition, the third structure houses an exhibition space that anyone can visit to see periodical art events (A). This construction is placed on a cast base.

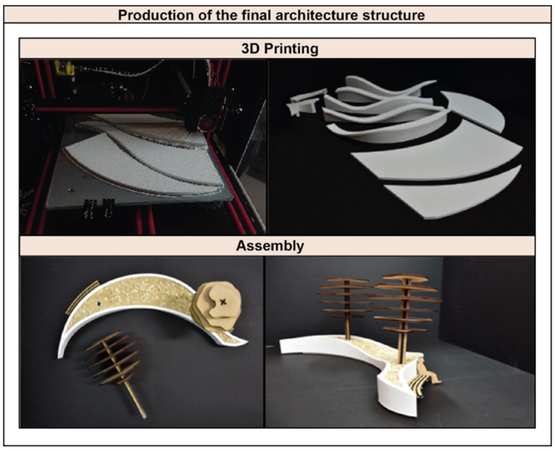
In the parametric modelling, the design process is based on algorithms which are a set of steps for a computer program to accomplish a task, and often come from computer programs such as Rhino3D™ and Grasshopper™. Normally in parametric design, the formation of the three-dimensional form is based on algorithms and rules, which result from the computer programs used. During the design process- it is worth to write down that the designer himself becomes responsible for the final decision of the resulting form, through all these conditions, parameters, and rules. Figure 8 presents view of the created code for the design of the first architecture structure, which has three sections.



» **Figure 8:** *3D digital model*

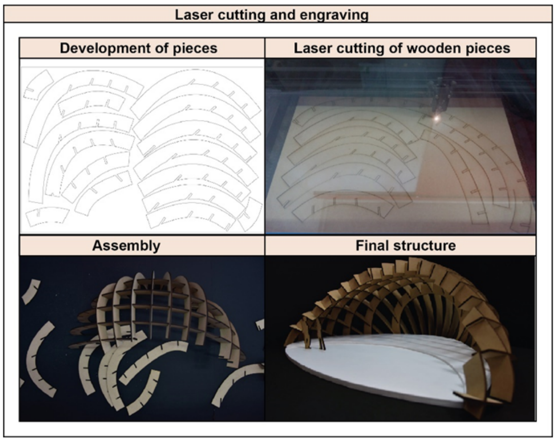
The commands Boundary Surface, Offset Surface and Extrude were used for the creation of the Section A (exhibition space). These specific commands are suitable for the proposed design and building approach. The development of Section B (green space) was based again on parameters on Boundary Surface, Offset Surface and Extrude. The reason of this decision was the similarity of these two forms (curved morphologies). On the other hand, the Section C (shell) is more complex and unusual geometry. The development of Section C was based on Python™ programming language (usage of rhinoscriptsyntax module for Grasshopper™) . Some of the commands were used for the script are: Extrude-CurveStraight (inserts values for extrude), OffsetSurface (inserts values for offset), MoveObject (moves planars for layering) and IntersectBreps (creates segments). The suggested example of Section C is based on laser CNC cutting techniques – in order to create wooden structures for architectural and product design purposes. All three structures are properly lit with spotlights, so that they are accessible to the public at night. Moreover, the rendered 3D model is depicted in this figure.

Following the final step in the process of product development is the production of the physical prototype with a reduced size model scale 1:20. The proposed methodology includes the production of the final architectural structure through rapid prototyping, laser cutting and engraving techniques. In this way, with the use of laser cutting machines and 3D printers (FDM printing technology), an additional benefit was provided for the understanding of the form, but also for any errors that occurred during the design. The sections A and B (exhibition and green space) were printed, and two physical forms were produced. The equipment for the proposed procedure of 3D printing was an FDM-technology 3D printer. The brand of the equipment is a Cubicon Style and the supported software for the slicing is Cubicreator v3.6+. The 3D models were layered and then printed in detail based on white colored PLA material. PLA is a popular material in 3D printing, enjoyed due to its more environmentally friendly nature and ease in use. The main parameters of the proposed procedure are a) infill percentage (20%), b) layer thickness (0,2mm), c) printing speed (20mm/s) and d) printing temperature (190°C). The parameters apply to both 3D printed models (sections A and B). It is worth emphasizing that the importance of synergy between design and printing-cutting systems, offering easier, faster, and cheaper assembly and construction. Figure 9 presents steps of structure production using 3D printing technology and assembled parts to create the structure.



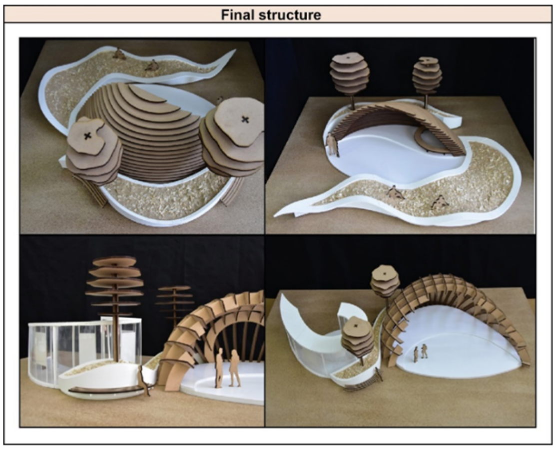
» **Figure 9:** *3D printing and assembly of the one structure*

The other part of the structure is a shell with wooden elements which are designed and exported for laser cutting. Figure 10 presents steps from piece development laser cutting process of elements, assembling of wooden elements and the resulted structure.



» **Figure 10:** *Various steps followed during the production of the structure*

The designer tested the original prototype of his customized design and sense the increased experience of a physical model versus a digital rendered CAD model. The physical prototypes produced using the technologies presented above are arranged together according to 3D virtual model. Figure 11 presents view of the created architecture structure taken from different positions.



» **Figure 11:** *The prototype model of final design approach in different view*

Conclusions

The present paper examines the holistic product design approach from design thinking methodology to product development framework. The research examines the aspect of architectural structures as results from the combination of design language elements (shapes and morphologies) and computational design tools. The main core of the concept was to redefine the creation method of complex structures according to language rules and computational design parameters.

The proposed methodology offers a series of great design and marketing advantages to designers that would be willing to adopt this design procedure: a) ease in the formation of new compositions, b) improved aesthetic perception and c) possibility of different compositions depending on the desired result. This paper combines the use of the parametric design methodologies and sketching styles according to lines, shapes, and structures in ideation stage of product design procedure. The basic reason of this approach is developing innovative and unique architectural structures under the main theme of the designers abstract sketching notes. In addition, through the use of parametric design, design techniques and the new design language, innovative architectural forms emerged. In conclusion, the design and construction of these proposals in public spaces is considered important, giving them a special architectural character, allowing the public to use them during their stay.

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The design and development of stop motion armature for a wide variety of applications

ABSTRACT

The development of prototype stop-motion armatures for a wide variety of applications commonly involves the use of metal, stainless steel, and brass. This research aimed to design stop-motion armatures using new materials and concepts for both basic and advanced stop-motion animations and to design the armatures to be fit and relevant to the characters that were made according to physiology and flexibility in use with a variety of functions. The present research used research samples consisting of 6 experts in materials, industrial designers, and designers of animation movies. They were asked to examine, edit, and evaluate the product prototype. The instruments used in the research were in-depth interviews and questionnaires. The data were analyzed by using mean and standard deviation. The results of the research are as follows: 1) regarding the development of stop-motion armatures, there were 9 armature models; 2) based on the research, test, and experiment, the suitable material was polyamide or nylon plastic, which is flexible and durable. It was good for the movement and forming of the position of the characters firmly; 3) regarding the test of efficiency for these armatures, the overall evaluation was at a high level. The mean score was 3.52, while the standard deviation (SD) was 0.43. The design of these stop-motion armatures shows a distinctive point in that they can be produced in industrial systems with a large number of items made at the same time. Further, this production process makes the armatures able to be fully modified or adjusted according to the characters designed.

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Armature, stop-motion, animation, industrial design

Introduction

"Economy is driven by innovation" is an expression that implies the economy creates wealth through science and technology, culture, and creativity. It also creates products that are "innovative" in order to adapt and respond to changing economic conditions. Increasing the capacity of technology and innovation, creativity, and business leads to intellectual property, added economic value, and meeting the needs of the labor markets, both domestically and internationally. Nowadays, the animation media market is considered the main media for disseminating, persuading, and presenting the cultural stories and civilization of nations (Liu, 2007). Animation is a universal media that can be accessed by people of all nations and languages. Although each nation and culture may have a different language, animation is a visual language that is expressed through personality, gestures, facial expressions, and emotions, making it something that is easy for viewers, both children and adults, to understand. This makes animation popular, and people of all ages appreciate it. In addition, it is also prevalent like movies that are part of the language (Kivy, 2004).

Stop-motion is another animated filmmaking technique that helps to convey the story of the animation. In the past, studies of robotics and computer graphics were significantly accepted in the description of movements of stiff body by using armatures for the animation characters (Singh & Singla, 2016).

To be completely successful, it is impossible to ignore or overlook the importance of anatomy when designing characters, both in the structure of people and other creatures. For example, when a steel company wants to create armatures and mechanical tools of dragon characters, it needs to use specific steel tools, have expertise, and be well trained in the use of steel working tools, which may be apart from animation work. It is because these aspects are necessary to be used in working on rotating joints and ball joints at the wrist and elbow axis. This requires consultation with knowledgeable and experienced experts who work in the steel-making industry and cutting work since it will help to improve the work to be better and faster. These experts work at full capacity with intelligence and knowledge so costs can be controlled appropriately. However, these experts are not stop-motion designers, so they cannot give recommendations about anatomy, creating the characters properly, or the working of the muscles covering the mechanics structure for the rotation and elbow movement at various pivot points and behind the elbow that there are more points than the wrist pivot points. These qualities require the ball joints to be made, and this mechanism is a very active form in the armatures that can create curving, twisting, and moving muscles that are made from foam, which finally covers the entire structure of the armatures. This is a realistic style of work creation.

There is also the observation about how to make the armatures (skeleton) fit and relevant to the designed characters. It can be observed from the moving joints and the bending of the muscles from the skeleton that creates the mechanical system used for the armature. It is controlled and performed in an anatomical form, which creates physical characteristics and the personality of the characters. Regarding the forms of the hand and leg systems created for people, horses or dogs, before designing various parts of the mechanical system, it needs to be studied, analyzed, and researched to understand the physiology. This study aims to answer the question and solve many doubts about character design by sketching the characters. Besides, this can help to understand various perspectives and proportions as well as provide clarity. Importantly, the muscles will change their shapes when twisting and turning for the continuation of the arms in rotation, so it is also necessary to make the pivot point around the elbow rotate back. This results in the armatures being able to twist their arms and latex foam, which is a type of rubber used to make the texture of the armature, and be bent like the real muscles of living things. If it is not possible to create a pivot point at the elbow area, but create the twisting of the arm around the wrist movement, it will cause a very tight twist on the wrist, which does not correspond to reality or the nature of the design of the armatures. Moreover, the joints must not be overlooked or abandoned in the designing and making of characters. It is crucial to understand anatomy, motion, and complete movement. As can be seen from world-renowned sculptors such as Michelangelo and Rodin, artists provide good examples of masterpieces that arouse people's interest and express the differences in concepts, forms, methods, and eras as well as the decision-making process for creating each masterpiece (Brierton, 2002).

For the reasons mentioned above, the researchers aimed to develop a prototype for a stop-motion armature that could be used in a wide variety of applications. Generally, they are made of metal, stainless steel, and brass. This requires expertise in the use of hand tools for various metal work and the design of stop-motion armatures for those who are not experts or work in metal work with new materials and concepts developed for stop-motion animation, both basic and advanced levels. Besides, the armatures must be designed to fit and respond to the personality of the designed characters according to the physiology and flexibility in use with a variety of functions.

Research objectives

1. To study and analyze stop-motion armatures for animation work that can be produced in an industrial system
2. To develop and design stop-motion armatures for animation work and develop materials and production processes suitable for the industrial system
3. To evaluate the efficiency of the prototype stop-motion armatures

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Literature review

The researchers reviewed, synthesized, and analyzed 12 patterns/models of armatures in the markets before designing and developing the stop-motion armature in the present research, as shown in Table 1.

From Table 1, the researchers selected and compared 12 stop-motion armatures for a review to identify their characteristics, strengths and weaknesses, and uniqueness of the armatures as preliminary information for the design of the new structure of the armatures in order to be unique, find the differences, and develop a usability based on the reviewed stop-motion armatures. The data are summarized in Table 2.

Table 1 (part 1)

A summary of material and property analysis and parts of 12 stop-motion armatures

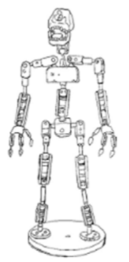
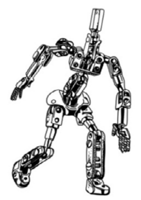
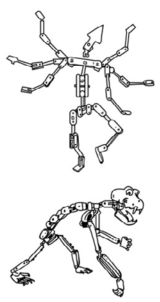
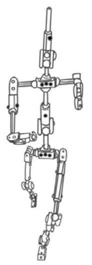
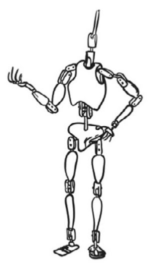
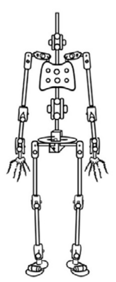
Armatures	Armature Forms	Materials	Strengths	Weaknesses	Joint Forms
1. Cyclops (Harryhausen, n.d.)		It was made of metal with joints on the body parts consisting of steel balls. The head is made of resin plastic.	The materials used are strong and durable.	The overall structure is fixed and created for one character only. It can easily rust.	All joints are steel balls, and the sockets are iron sheeting attached with welded bolts.
2. Armature by Ted Sydor when he was a student at Middlesex County College, New Jersey in 1991 (Trik Film Effects, 2010)		It was made of plastic and wood, about 10 inches tall, using bolts to hold the parts together with the use of plastic ball joints.	The structure is easy to assemble by hand.	Plastic sheets at the joints are easily twisted. The ball joints are plastic, causing the rotating joints to have a lot of friction.	All joints are plastic balls, and the sockets are made of plastic sheets connected by bolts.
3. Armature (Brierton, 2018)		It was made of various metals such as aluminum, steel and materials used to build spacecraft, which are lightweight, highly durable, and flexible; 50% lighter than aluminum.	The materials used are strong and durable.	It has a specific and fixed structure that is difficult to assemble, requires cutting tools to cut according to size, and must be assembled according to the design model.	All joints are aluminum balls, and the sockets are made of aluminum sheets connected by bolts.
4. Armature (Kawamura, 2019)		The main structure is aluminum, the socket is made of phosphor bronze plate, and the ball head is made of ordinary steel, which is rust-proof.	The materials used are strong and durable.	It has a specific and fixed structure that is difficult to assemble, requires cutting tools to cut according to size, and must be assembled according to the design model.	All joints are aluminum balls, and the sockets are golden phosphor bronze plates connected by bolts.
5. Armature (Animation Toolkit, 2018a)		It is polished stainless steel with 24 joints. Many points were designed according to anatomical design and 3D printed muscle structure.	The internal structure is polished stainless steel, which is strong and durable.	It has a specific and fixed structure that is difficult to assemble, requires cutting tools to cut according to size, and takes a lot of time to assemble.	All joints are stainless steel balls, and the sockets are stainless steel plates connected by bolts.
6.Armature Creature Kit (Animation Toolkit, 2018b)		It is made of more than 100 pieces of stainless steel, 20 rust-proof type metal joints, hardened stainless steel ball head, and socket head bolts that have magnets embedded at the tip of the foot.	The materials used are strong, durable, and lightweight.	It has a specific and fixed structure that is difficult to assemble, requires cutting tools to cut according to size, and takes a lot of time to assemble.	All joints are steel balls, and the sockets are stainless steel sheets attached with bolts.

Table 1 (part 2)

A summary of material and property analysis and parts of 12 stop-motion armatures

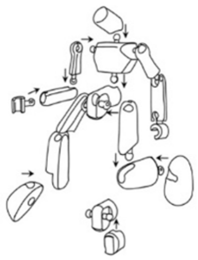
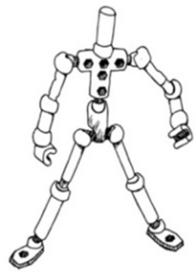
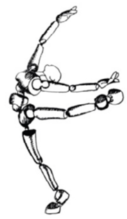
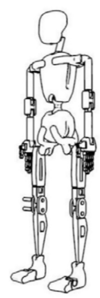
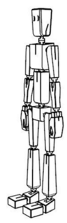
7. Stikfas (LNCollections LLC, 2008)		It was made of hard plastic from Hasbro's industrial plants, with plastic pieces that are easy to make and change.	The Stikfas has all the ball joints, and the sockets are easy to make and assemble, but not easy to fall off.	- The posture and movement are not very good since the socket supports one-sided bend only. - The joints are not fully bent and folded, such as the folding of the knees that can be done only 30-45 degrees. - There are no clavicle bone joints or finger joints.	All joints are balls. The sockets are balls sized 2.5 mm wide.
8. Modibot (ModiBot, 2019)		It was created from 3D printing, which can use a variety of plastic filaments, such as PLA, ABS, including printing with resin plastic.	In 3D printing, a variety of materials can be chosen for use.	- The posture and movement are not very good since the socket supports one-sided bend only. - The joints are not fully bent and folded, such as the folding of the knees that can be done only 60-90 degrees. - There are no clavicle bone joints or finger joints.	All joints are balls. The sockets are the same big and thick in all parts so that they can be connected in a variety of sizes. The ball size is 6 mm. The socket balls are 8.5 mm in size.
9. Stickybones (Stickybones Inc., 2019)		It was created from a 3D program and printed with a resin printer. After that, it was scrubbed to smooth the surface, painted, and lasered to make the colors more firm and durable.	A variety of gestures and postures can be set up. Knees and arms can be bent and folded up to 10-15 degrees.	- The overall structure is the same size as human proportions, which are fixed in appearance and unchangeable. - The hands and feet are bigger than the actual human physique.	All joints are balls. The sockets are large and thick at specific points, especially the parts that support weight, such as the feet, chest and waist. The joints of the fingers are small and have all 5 fingers.
10.Armature Nine (A9-RIG) (A9 Products, 2020)		The surface is a combination of a variety of materials, such as wood composite, and is produced from 3D printing using ABS plastic. The joints are made from resin 3D printing.	- Most joints are ball joints, and the sockets, except for the knees, use bolts to increase the strength. - It looks like a real human. There are joints on every finger.	The joints are more than necessary. The clavicle bone joints and thigh joints are too large, so it is not very easy to move.	- The head joints, arms, fingers, and ankle joints are balls and sockets. - Clavicle bone joints and pelvis joints are serrated spurs and can be rotated in 2 directions. The other side is a ball socket. - There are 2 types of knee joints: the top is the ball and the socket, and the knees are plastic sheets connected by bolts.
11.Gemobot (Nattotoys, 2017)		The surface is printed with ABS plastic. The joints are metal ball joints. The hands are made of flexible plastic.	The movement of the steel balls and the plastic sockets work well, with inertia acting on ABS plastic.	- The bending of the knees and elbows is not very good, and it can only be folded to a minimum of 45 degrees. - The body cannot be bent since it is a square that has angles that make it unable to bend.	All joints are steel balls, and the sockets are plastic with a central notch.
12. Skelly the Skeleton (Lane, 2018)		It was created from 3D printing, which can use a variety of plastic filaments such as PLA, ABS, including printing with resin plastic.	In 3D printing, a variety of materials can be chosen for use.	- There are no clavicle bones, and the neck next to the body is unable to bend. - The pelvis is too narrow, so the socket cannot rotate the leg. - There are no finger joints.	All joints are balls. The sockets are big and thick. All joints are equal, which allows them a wide range of connections.

Table 2

The comparison of 12 stop-motion armatures and the armature designed in this study

The main design features of the 12 stop-motion armatures	The comparison of these 12 stop-motion armatures and the armature designed in this study
1. The joint is a ball head, and it is a joint.	1. There is no difference in this point.
2. The material is strong and resistant to bending and moving of joints.	2. There is no difference in this point.
3. The metal materials such as iron, copper, aluminum were used.	3. The designed armature was experimented with metal and plastic materials, such as stainless steel, PLA plastic, and rubber. The problem is that the production cost will be higher in the whole working process, mold material, and working time
The main design features of the 12 stop-motion armatures	**The comparison of these 12 stop-motion armatures and the armature designed in this study**
4. Shape, proportion, and height must be produced and created only for each character.	4. The shape, proportion, height, and width of the designed model can be modified.
5. The Armatures made from various metals require high craftsmanship skills in metalwork and can be built at a high cost and time consuming with a low production number.	5. The designed armature can be manufactured as a prefabricated part which can be assembled without requiring very high building skills and can be produced in industrial system with a high number.
6. Some new materials have been developed to be produced massively and industrially.	6. The designed armature was tried out with new materials, such as PLA plastic and nylon plastic in the production.
7. The folding joints, such as elbows and knees joints generally cannot be bent up to 180 degrees.	7. The folding joints, such as elbows and knees joints are developed to be bent up to 180 degrees.

Research method

This research has developed and designed a stop-motion armature for animation work so that it can be produced in an industrial system. The design process required a stop-motion armature for people who did not have knowledge and expertise in a metalworking field. In addition, it required flexibility in a variety of functions and a uniqueness in design. The details of the research process are as follows.

Step 1: To study and analyze stop-motion armatures for animation work that can be produced in an industrial system

It started with reviewing documents, textbooks, research findings, research methods, and designing and making processes related to stop-motion armatures. 12 models of armatures from armature structure companies and films in the markets were chosen, synthesized, and summarized. The design framework was then created to be different and unique. After that, the interviews with 2 experts in designing animated films using stop-motion techniques and 1 industrial designer were conducted. The examples of the in-depth interview questions are: 1) What are the problems and needs for materials and the design of stop motion armatures? 2) What are the features of the stop motion armature design?, and 3) What precautions do you have in the industrial production system regarding the design of stop-motion armatures? The researcher then analyzed the data obtained from the interviews and presented them in a descriptive form.

Step 2: To develop and design stop-motion armatures for animation work and develop materials and production processes suitable for the industrial system

After the conceptual framework for the design of stop-motion armature was made, and the in-depth interview data were obtained, these data were used to select the material and design together with various material experiments to use in the prototype armature. The experimental materials were ABS plastic, PLA plastic, and Nylon plastic which are materials commonly used for 3D printing and stop-motion armatures. Additionally, these materials were suitable for use in injection molding in industrial production systems. Then, the product prototype was made using 3D printer technology (Loy, 2018). Fused deposition modelling (FDM) and LCD 3D Printer were employed and experimented with metal materials, including stainless steel, aluminum, UV resin, and rubber materials. There were 9 different models. These models were then tested and evaluated by in-depth interviews with 4 experts consisting of 1) 2 animation designers, 2) 1 animation director, and 3) 1 product designers. Data obtained from the interviews were summarized. One model of stop-motion armature was selected, developed, and edited in the final stage.

Step 3: To evaluate the efficiency of the prototype stop-motion armatures

After developing and editing the prototype, a 3-minute stop-motion animation was made in order to test the movement of the armature and find a development conclusion. The results were then evaluated by using a Likert

Scale questionnaire by 6 experts consisting of 2 animation designers, 2 animation directors, and 2 product designers. The evaluation was emphasized on 4 aspects, including the design process, the usability of stop-motion armature, the determination of posture and movement of the stop-motion armature, and the standard of the production and development of the stop-motion armature. The data were then analyzed quantitatively.

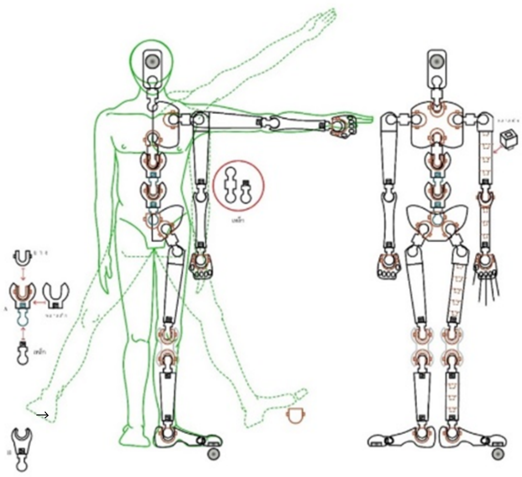
Results

The research findings are shown below according to the research phases mentioned above.

Regarding Research Objective 1, it was found that, in terms of shape design, there were shapes that were the same as human proportions and could be adjusted according to the character design. For example, 1) in the joint areas, the main parts were the ball joints and the ball sockets for the movement around the joints, 2) parts of the elbows and knees could move freely and follow the natural movement of living organisms, as found in Janma (2003), and 3) the materials mostly used from research studies in stop-motion animation industry were metal, such as aluminum, stainless steel, and brass, followed by PLA plastic, which has elastic properties and is resistant to friction.

Regarding Research Objective 2, the researchers designed 9 stop-motion armatures and experimented with different materials, beginning with plastic. From the concepts and rationale supporting designs that require a large amount of industrial production, it was reinforced to use aluminum materials in ball joint parts for adding strength and being resistant to friction between the joints when moving. After that, the researchers developed the stop-motion armatures by adding plastic materials that are flexible and resistant to twisting, folding, and bending when moving. Consequently, it came into the final form based on the advice of experts and consultants as well as agreement. That is, the researchers should use only nylon plastic material in the production of the armatures according to the reasons mentioned above.

After that, the researchers did a sketch design by taking the form of the bone structure and the human anatomy as a guideline for drafting and developing in order to be similar in terms of shape, proportion, function, and various movement methods of parts around the joints, as well as the main bone parts in the human body structure and other bipedal animals. This made the design work similar to the skeleton structure and the armatures studied. However, new concepts were also added regarding the need for the armatures to be designed with the ability to be modified with flexible proportions and adjustable for height- low to get the desired size, while the proportions in the characters could increase or decrease by themselves, such as the length of the arms, legs, neck or body. In designing the stop-motion characters, the users would be able to increase the number of different sections of the body, such as adding more than two arms, legs, or wings to the characters as well as adding head and tail parts. This aimed to increase the functionality of the stop-motion armatures and provide greater flexibility in the design. Moreover, it enabled the creation of animation work with new character designs. Finally, the designed armature was developed as shown in Figures 1-3. These stop-motion armatures are independent and can be adjusted and modified further, such as height proportion, the number of additional arms and legs, and additional parts such as tails and wings. This is considered a new design that is different from those currently available on the market.



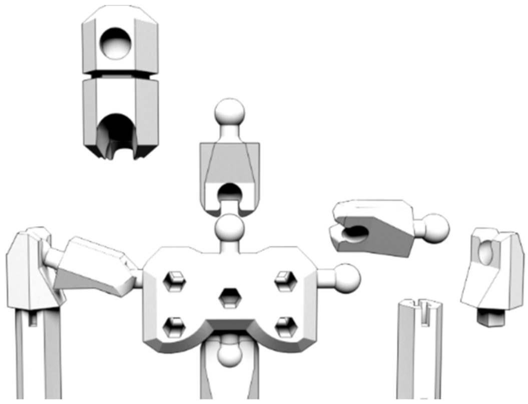
» **Figure 1:** *Sketched and designed work for the stop-motion armature*

» **Figure 2:** *Final designed work of the stop-motion armature*

The concept of the design, function, and features of various parts of the stop-motion armatures that were redesigned and developed are as follows.

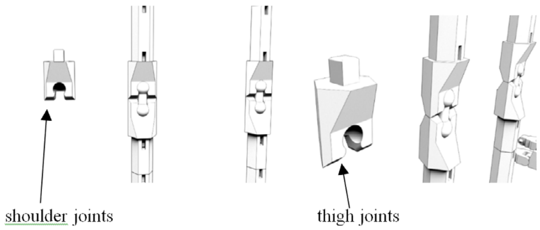
- The head and head area of the armatures can be adjusted in terms of size and proportion by having a slot as an extension to increase the height. From this concept, it can be adjusted according to the work of various character designs, as shown in Figure 4.

» **Figure 3:** *Stop-motion armatures that are independent and can be adjusted and modified*

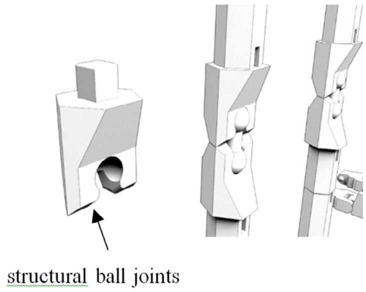


» **Figure 4:** *Details of head, chest, and shoulders of the stop-motion armature*

- Shoulder joints, thigh joints, and the parts in this area can be substituted, as shown in Figure 5. In Figure 6, the structural ball joints can be connected to ball joints with ball socket holes. These joints are the same joints. They can be adjusted into shoulder joints, knee joints, elbow joints, and all foldable joints. Also, the adjustment of the angle to the position of the joints can be done to an incremental angle of more than 180 degrees. According to the reviews in Table 1, most of the joints will be angled around 180 degrees or less.

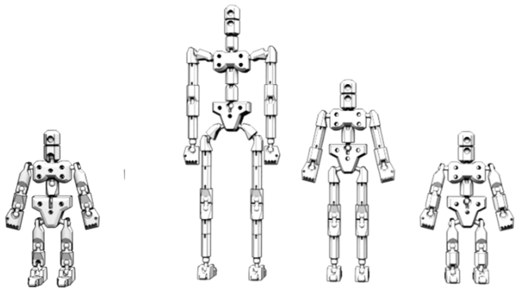


» **Figure 5:** *Details of the shoulder joints, thigh joints, and parts in this area that can be replaced*

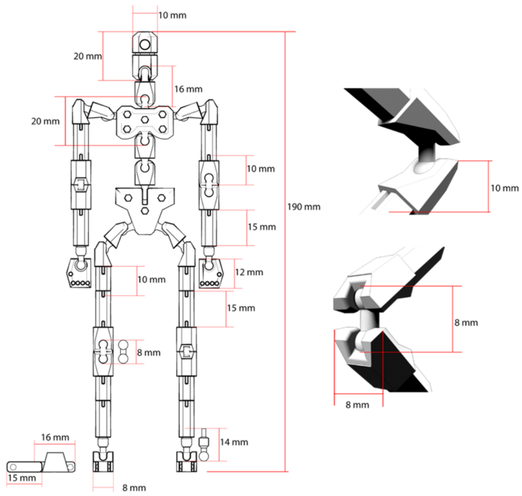


» **Figure 6:** *The structural ball joints that can be connected to ball socket holes*

- The joints that determine the proportions of the arms and legs can be adjusted to increase – decrease the proportion of the length and height of the character according to the designer's preference. In addition, the spine parts can also be adjusted to increase- decrease the height of the character, as seen in Figure 7. The important parts that have been designed and developed make the characters adjust more easily since there are joint pieces that can adjust the height and add organs. Figure 8 shows the sizes and proportions of the armature in greater detail in millimeters.

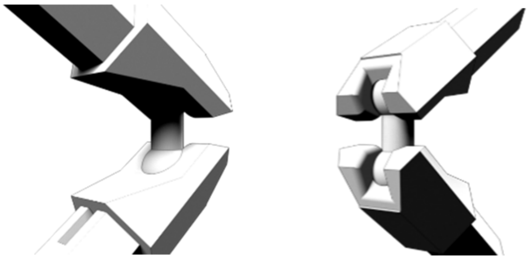


» **Figure 7:** *The joints that can be adjusted to increase or decrease the proportion of the length of arms, legs, and the height of the spine*

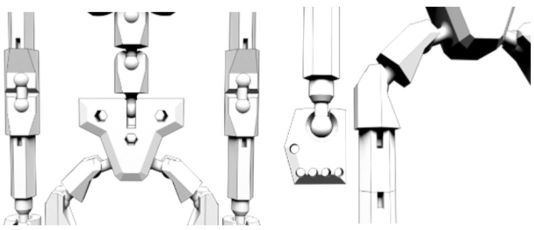


» **Figure 8:** *The sizes and proportions of the armature in millimeters*

- The joints on the elbows and knees in this new design use the concept of physical work. The elbows and knees are designed to bend more specifically to 180 degrees. The design of the joints that wear to the ball can bend more than other joints in order to increase the realism of posture, which can make the armatures move more effectively, as shown in Figure 9. Figure 10 shows the structural parts of the hips, hands, and thigh joints.

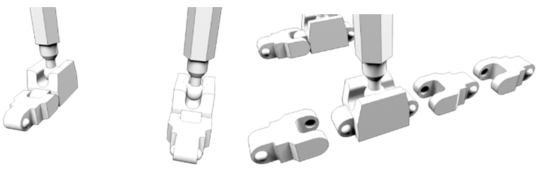


» **Figure 9:** *Elbow and knee joints that can be bent more around 180 degrees*



» **Figure 10:** *Structural parts of the hips, hands, and thigh joints*

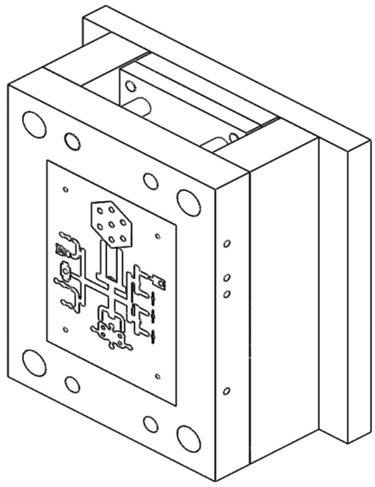
- For foot pieces, the length and width can be adjusted according to the length of the character's feet, as shown in Figure 11.



» **Figure 11:** *Foot parts and additional parts*

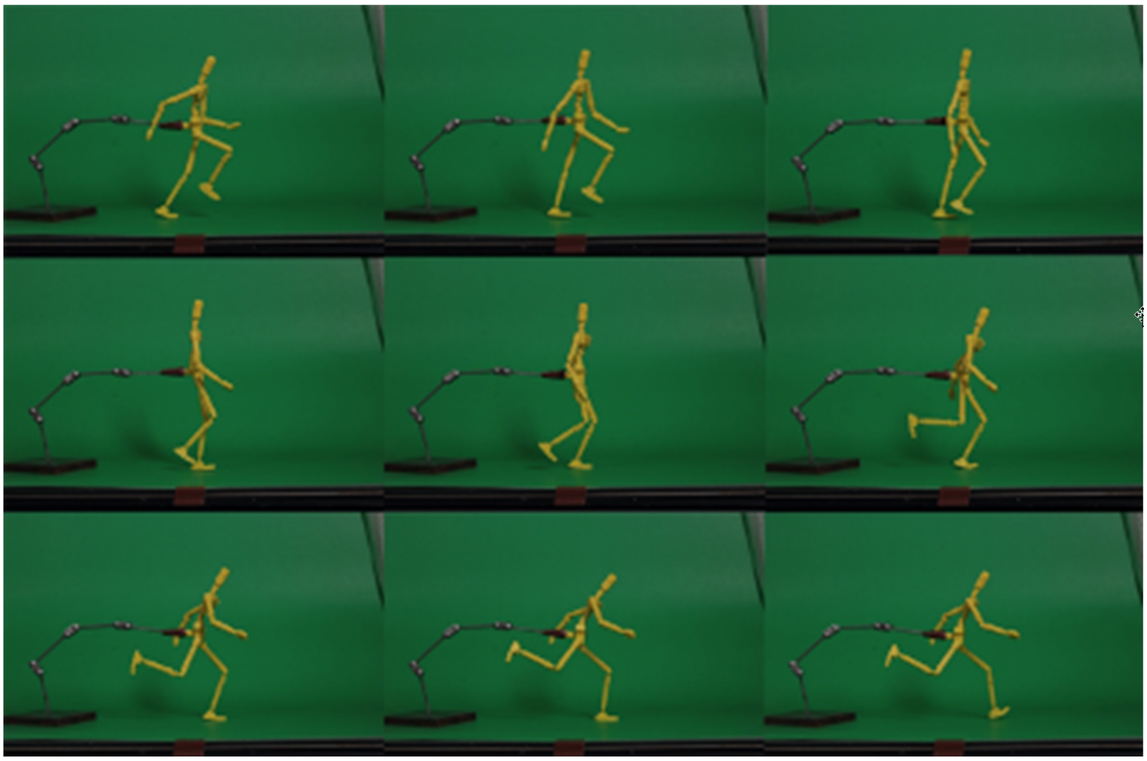
- When the prototype had been obtained from a 3D printer, the researchers there after studied the production process and mold design of the stop-motion animation at the industrial level. The researchers chose to use the injection molding process. The principles of the injection molding production process can be explained as follows. Firstly, it started with adding raw materials such as plastic granules or powder into the filling cone. In this research, polyamide or nylon plastic was used to be sent to the front of the cylinder, which has an electrical heating plate that causes the plastic to melt and be forced to move to the tube through the nozzle and into the mold, which is closed. The mold, which is cooled by cold water produced from a chiller, will cool and harden the workpiece, allowing removal of the mold from the model in a short time. Then, the work is sent to decorate, as seen in Singh and Verma (2017). In this research, nylon material was chosen because this type of plastic has outstanding properties in terms of strength, toughness, tensile resistance, and resistance to corrosion as well as abrasion. It is not easily deformed, making it suitable for very strong work. In this research, there were many components (joints) that needed to be assembled to use in moving the armatures many times. Therefore, it was necessary to use plastic that is resistant to friction among the joints, which would affect the strength and durability of the stop-motion armatures.

After that, the researchers created the industrial drawings of the stop-motion armatures and the mold of the stop-motion armatures, as shown in Figure 12, which is a mold for casting an armature designed for mass production with nylon material injection molding and bringing the sub-parts together to form a complete full-body armature. The researchers also filed a patent for the armature and the mold made in Thailand as a research innovation.

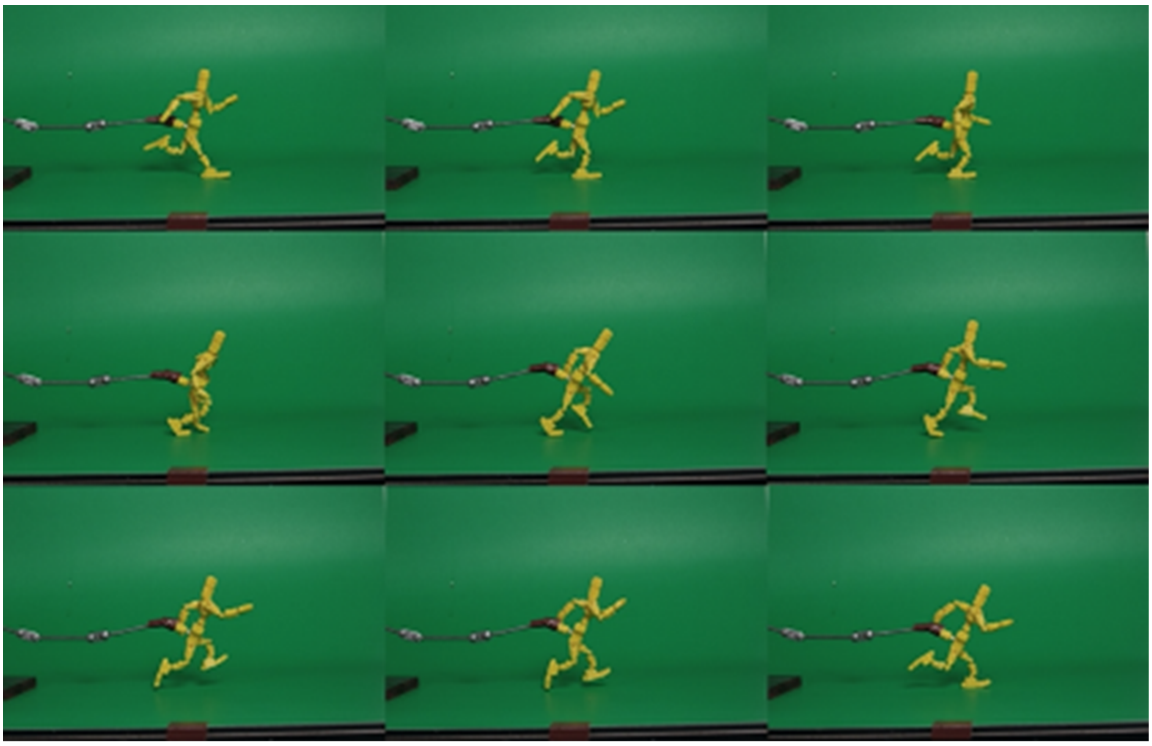


» **Figure 12:** *Injection molded parts designed in this research (Injection Molding)*

Regarding Research Objective 3, the results of testing and evaluating of the stop-motion armature prototype from research advisors and experts are presented below. For the results of testing the postures and movement (animated), it was found that this designed armature could determine the motion, arrange movements frame by frame in order to be arranged in an editing program, and create animation. This led to the illusion that the stop-motion armatures could move and be lively as characters designed to express emotions, postures, movements, and gestures. In this experiment, the researchers determined the basic movements needed to create movement, such as walking and running by the armatures, with different shapes and proportions, as shown in Figures 13 and 14.

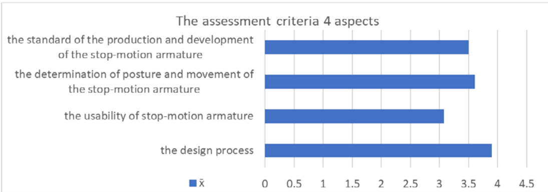


» **Figure 13:** *Example of determining the basic movements as Walk Cycle armature*



» **Figure 14:** *Example of determining the basic movements as Run Cycle armature*

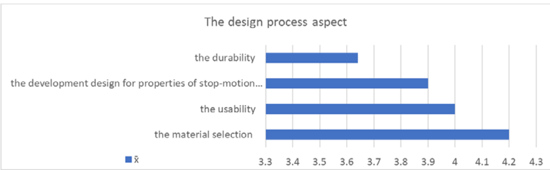
The assessment criteria of the stop-motion armatures prototype design were divided into 4 aspects: 1) the design process, 2) the usability of stop-motion armature, 3) the determination of posture and movement of the stop-motion armature, and 4) the standard of the production and development of the stop-motion armature as shown in Figure 15. The results of evaluating of the stop-motion armature prototype from research advisors and experts showed that the overall effectiveness was at a high level (x̄= 3.52, SD = 0.43).



» **Figure 15:** *The assessment criteria 4 aspects*

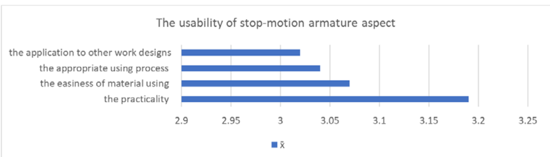
When considering in greater detail, the results of each aspect are as follow.

1. Regarding the design process, the overall effectiveness of the stop-motion armature was at a high level (x̄=3.9, S.D.=0.60). When looking in greater detail as shown in Figure 16, the material selection was rated the highest (x̄=4.2, S.D.=0.54). It was followed by its usability (x̄=4.0, S.D.=0.65), the development design for properties of stop-motion armature in terms of physical features (x̄=3.9, S.D.=0.38), and its durability (x̄=3.64, S.D.=0.79), respectively.



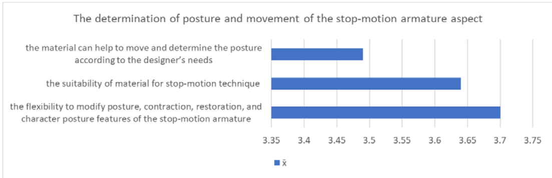
» **Figure 16:** *The design process aspect*

2. Regarding the usability of stop-motion armature, the overall effectiveness was at a medium level (x̄=3.08, S.D. =0.45). When looking in greater detail as shown in Figure 17, the practicality was rated the highest (x̄=3.19, S.D. = 0.44). It was followed by the easiness of material using (x̄=3.07, S.D. = 0.32), the appropriate using process (x̄=3.04, S.D.= 0.44), and application to other work designs, such as product design and craftsmanship design (x̄=3.02, S.D.=0.60), respectively.



» **Figure 17:** *The usability of stop-motion armature aspect*

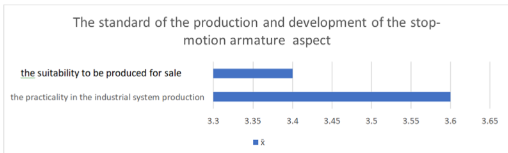
3. Regarding the determination of posture and movement of the stop-motion armature, the overall effectiveness was at a high level (x̄=3.61, S.D. =0.45). When looking in greater detail as shown in Figure 18, the flexibility to modify posture, contraction, restoration, and character posture features of the stop-motion armature that can convey emotions and meaning of the character the highest (x̄=3.7, S.D.=0.31), It was followed by the suitability of material for stop-motion technique (x̄=3.64, S.D.=0.51), and that the material can help to move and determine the posture according to the designer's needs (x̄=3.49, S.D.=0.53), respectively.



» **Figure 18:** *The determination of posture and movement of the stop-motion armature aspect*

Moreover, in moving the joints and posturing this animated stop-motion armature, the researchers had moved the joints more than 1000 times (estimated by movement postures of proportions to generate 25 frames per second). For the movement postures, both walking (Walk Cycle) and running (Run Cycle), the amount of each movement was approximately 30 seconds (30 x 25 frames equal to 2 movements, moving more than 1500 times). The firmness, stability, not expanding the size of various joints, and frictional resistance without breaking, bending, cracking were achieved without any effect on this stop-motion armature. This confirms that plastic materials such as Nylon are suitable for use.

4. Regarding the standard of the production and development of the stop-motion armature, the overall effectiveness was at a high level (x̄=3.50, S.D. =0.23). When looking in greater detail as shown in Figure 19, the practicality in the industrial system production was rated the highest (x̄=3.60, S.D.=0.25). It was followed by the suitability to be produced for sale (x̄=3.40, S.D.=0.21).



» **Figure 19:** *The standard of the production and development of the stop-motion armature aspect*

In this research, there are suggestions for further research as follows.

- The shoulders are too convex. As a result, they will tear when covered with plasticine. Therefore, the surface should not be smooth so that there will be more adhesion of the plasticine and other materials.
- It should be used and broadcasted as a short film, including showing the making of these designed armatures (behind the scenes).
- It should be applied to use with a variety of materials, such as plasticine, silicone, and so on.

Conclusion and discussion

In this study, there was a clear objective in terms of designing the stop-motion armatures in order to be able to be produced in large numbers at the same time and be suitable for industrial production in terms of design, shape, and materials used. Besides, the design is different from general armature designs that are available in the market and in the industrial system. That is, these stop-motion armatures can be modified, adjusted, modified for height- low proportions, and given additional parts such as arms, legs, tails, wings, and various functions, which can be changed appropriately and freely according to the shape and proportion of the character designs by designers and animators. As Harryhausen and Dalton (2008) noted, many great movies use animation for the characters' movements. It takes a lot of time in order to find the best process techniques, practical guidelines, and methods that are appropriate according to the desired concept. This is in line with Shen (2007), who said that using technology and tools is just one way to communicate the main story, convey the social and cultural meaning, and create cultural meaning through varied understanding of visual media by observing the true story in order to support the traditional ideals and Western concepts that movies attempt to convey as reality.

In addition, the concept of designing the joints for the stop-motion armature should be similar to the natural movements of living organisms and the principles of animation to create characters that are realistic. This is consistent with Castells and Fonseca (2009), who noted that the creation of animation characters can be linked to the archetypical concept of Carl Gustav Jung, which uses ancient personality patterns. Characters of the same type appear at any time and in every culture in history, resulting in a universal model and the exchange of experiences in different historical events.

This can be seen as a universal language, as mentioned by Floquet (2006) in the article on text theory proposed by Roland Barthes that "every text is inter-text; it holds other texts within, at various levels and in irregularly recognizable shapes. Other texts that are combined are from preceding cultures, as well as the surrounding culture. Every text is new, with interwoven past quotations" (p. 1). A text, film, or animated film is made and framed with gathering quotations that work together in the original feature. Moreover, a text, film, or animation absorbs, transforms, and creates its own text form.

According to Harryhausen and Dalton (2008), stop-motion animation is a valuable art that can show the beauty of human emotions, craft art, and handmade art. This makes the art of stop-motion animation techniques as valuable as High Art. Further, it can be expected to endure/exist in an era of technological change.

This experimental work will be used for working in the digital content industry in Thailand by studying and developing techniques. Then, it will be applied for work in stop-motion animated movies. It is another technique and another tool which could be an alternative leading to industrial production to support the animation industry and its continuing growth in Thailand.

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Preparation and application of rose oil capsules onto printable paper

ABSTRACT

In this study, rose oil was encapsulated with stearic acid substituted polyvinyl alcohol macromolecule. In the first part of the study, stearic acid substituted polyvinyl alcohol macromolecule was synthesized and its chemical structure was elucidated by ATR-FTIR and ^{1}HNMR. Then, rose oil was encapsulated using this obtained polymer. The chemical structure of the obtained capsules was made by ATR-FTIR, and dimensional analysis was done by scanning electron microscope (SEM). After the obtained capsules, a paper coating formula was prepared and coated on 80 g/m² paper. The resulting scented papers were printed using the screen printing technique. The color, gloss, and deformation of the capsules on the surface of the printed and unprinted papers were determined by spectrophotometer, glossmeter and SEM. As a result, it was determined that the synthesized polymer could encapsulate the rose oil and the papers using these capsules could be printed without deformation.

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Printability, encapsulation, rose oil, coating

Introduction

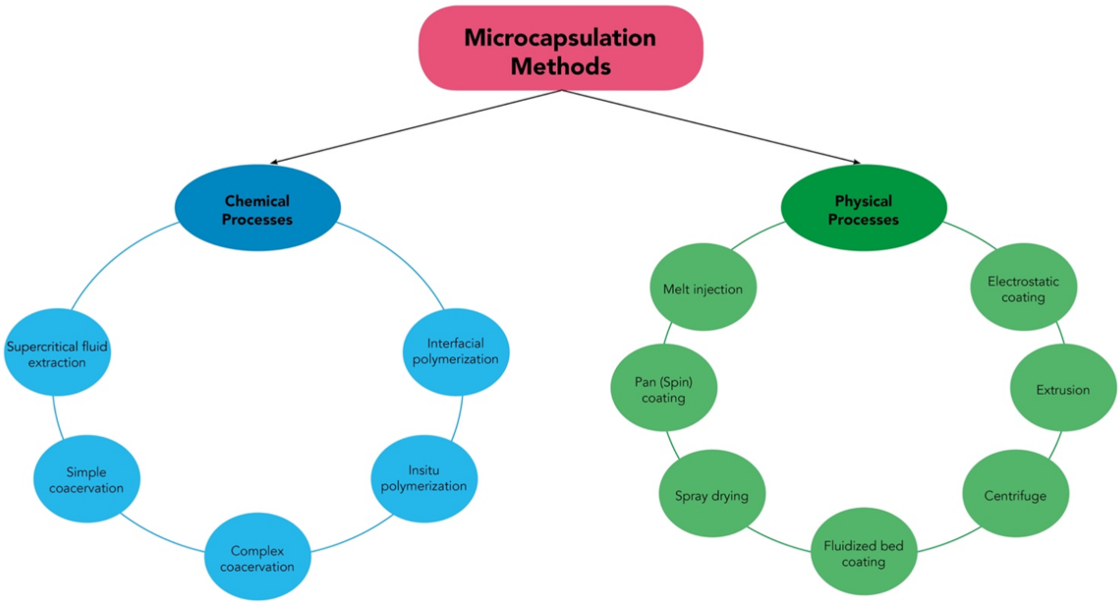
Products with added value affect the purchasing behavior of customers. Papers with scented properties are one of them. Fragrance comes with perfumes, essences, or scented oils. While fragrant oils have advantages such as being natural and being more intense, they have disadvantages such as their prices and low production efficiency. All odors lose their effect after a while in contact with the air. In this sense, odors must be preserved. One of the methods to be used in the storage of fragrances is encapsulation. In the encapsulation, the liquid, solid or gaseous odorous content is covered with a polymeric wall and is pressure-sensitive released at the desired time. In this way, both odor is preserved, and it can be distributed more easily in ink or coatings.Fragrances are materials that are frequently used in our daily lives to attract attention and increase appetite. Fragrances are quickly affected by external effects such as oxygen and light (Barret, Beaulieu & Shewfelt, 2010). For this reason, they decompose rapidly, and odors exposed to open air spread rapidly and move away from the material to be odorized, and the desired property is quickly lost. For this reason, the odor must be preserved until it reaches the end user. With the developing technology, microcapsules can be used effectively in the protection, storage and distribution of chemicals that are rapidly affected by the external environment, degrade quickly, and have problems of dispersion in the materials to be used (I Ré, 1998). Scented papers are used in many areas such as packaging papers, tissue papers, personalized products, or catalogs. Fragrances can be imparted to the paper by surface coating during or after the production of the paper. The biggest problem with scented materials that will be added to the paper content is the dispersion problem of the scented materials in the paper or coating formulation and the rapid loss of the scent. For this reason, microencapsulation can be made to produce scented paper, and the scent can be stored for a longer time and released at the desired time (Ichiura, Sakamoto & Ohtani, 2016). Many odorants can be obtained from natural sources. The obtained natural origin scenting materials can be essences or essential oils (Sharmeen et al., 2021). Due to the developing technology and the demand for healthy nutrition, return to nature and sustainability, the use of essential oils as fragrance materials is increasing day by day. Examples of essential oils used as fragrances are lavender oil, rose oil, peppermint oil, lily oil, rosemary oil, and geranium oil. Naturally sourced fragrant essential oils degrade rapidly, and it is seen as an effective method to produce microcapsules with natural shells to last until the end product use (Martins et al., 2014). The release mechanisms of encapsulated materials depend on the purpose of encapsulation. The encapsulated material can be released by external pressure, abrasion, heat, and diffusion (Milošević et al., 2017). For example, odors used in textile applications can be released by abrasion of the microcapsule wall in washing machines and dryers (Jyothi et al., 2012). Or scents applied on paper can be released by the effect of pressure. The encapsulation process provides a controlled release of fragrance compounds at the desired time. Relatively volatile components can be converted into stable components that inhibit rapid evaporation. In addition, the encapsulation technology provides environmental protection by reducing the waste of components. At the same time, material utilization and storage stability are improved by encapsulation (Ding et al., 2020). Timely and targeted release improves cost-effectiveness for manufacturers, thus improving desirability and marketing concept. Microcapsule production techniques are examined in two main groups as chemical and physical methods (Figure 1) (Jamekhorshid, Sadrameli & Farid, 2014).

In choosing the encapsulation method, the chemistry and properties of the inner and shell material, the diameter of the capsule, the permeability of the shell material, and the place and purpose of use of the capsule are taken into consideration (Augustin & Hemar, 2009).

Microcapsules have been frequently encountered in all areas of life for many years. The most used areas of microencapsulation applications are cosmetics, cosmetics textiles, paper and non-woven materials, graphic arts and printing industry, textile industry, special coatings and deodorants, food industry, detergent-phytosanitary products, biotechnology, electronics, medicine, pharmacy, agriculture, construction, waste treatment, chemical industry, photography etc. (Dubey, 2009).

With the addition of odor perception thanks to microcapsules to visual and tactile quality in printing technologies, we achieve more in terms of quality (Urbas et al., 2017). The value of products can be increased with prints where memories are recreated, emotions are enhanced, or scents with calming properties are applied. Microcapsules are often used in “scratch-n-smell” applications, such as perfumes in newspaper and magazine supplements, and stickers in “peel-a-part” applications, such as promotional advertising campaigns, children’s books, and cookbooks (Cleary et al., 2010). The main advantage of applying microcapsules with a specific printing technique is that the microcapsules can be applied to the target areas of the substrate and homogeneously (Starešinić, Šumiga & Boh Podgornik, 2011).

Fragrant essential oils that can evaporate at room temperature are materials produced from different parts of fruits and annual and perennial plants with strong aromatic odor properties. Due to their structure, they are available in very light yellow colors, which can evaporate in the liquid phase under standard conditions and can easily form solid crystals (Lee, 2003). These materials, which are also called essences due to their attractive odor, show etheric properties (Spence, 2021). These



» **Figure 1:** *Microcapsule production techniques* oils, which have a long chain organic structure, undergo phase separation with water (Dhifi et al., 2016). Oils are used in the preservation of food and beverages with their properties such as slowing and preventing decay, slowing oxidation, accelerating destruction, and accelerating the reaction with enzymes. Essential plant-based oils are generally defined by the U.S. Food and Drug Administration (FDA) as GRAS, or generally safe (Prakash et al., 2015). Essential oils are aromatic compounds widely used in the perfume, pharmaceutical, and food industries. Essential oils are a mixture of more than 200 different compounds. These compounds consist mainly of monoterpene and sesquiterpene hydrocarbons and their oxygenated derivatives such as esters, alcohols, aldehydes, and ketones (Arman Kandirmaz et al, 2020). The ingredients obtained from the rose are used in cell renewal, correction of deformation and in the treatment of some diseases. It is also known that rose extracts are used in the treatment of stress and anxiety disorders (Happy, Jahan & Momen, 2021). When the extracts obtained from the rose were examined, it was determined that the source of the odor was monoterpene alcohols linalool, citronellol, ethers and linear carbon compounds with high molecular weight, esters, and phenols. Apart from these, β-damacenone, β-damacene, β-ionene are among the components that contribute to the odor in trace amounts (Erbas & Baydar, 2016).

In this study, the encapsulation of fragrant oil produced from roses grown in Turkey with stearic acid substitute polyvinyl alcohol (PVA) shell material, the coating of the produced capsules on paper and the printability of the coated papers were investigated.

Materials and methods

Materials

Polyvinyl alcohol, stearic acid, sulphuric acid, and ethanol were obtained from Sigma-Aldrich Chemie GmbH, Switzerland. Rose oil was purchased from a local market. White color base paper was used in the study. The technical specifications of the base paper used in the study are given in Table 1.

Table 1
Technical properties of base paper used in the study

Properties	Standard	Base paper
Grammage (g/m²)	ISO 536	80
Thickness (µm)	TAPPI T411	177
Whiteness (D65/10) (%)	ASTM E313	97
Gloss (75°)	Tappi T480 OM-20	5.5

Methods

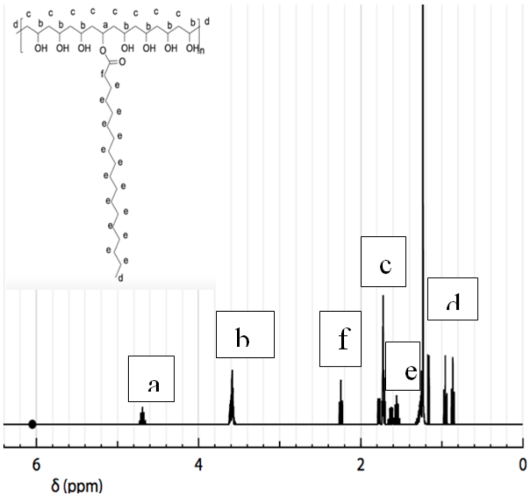
Stearic acid substituted polyvinyl alcohol polymer was synthesized by the acidic esterification method. For this purpose, PVA (40 mmol), 200 mL distilled water and stearic acid (10 mmol) were charged into a three-necked flask with nitrogen inlet, magnetic stirrer, thermometer, and reflux connected. While stirring in the oil bath at 250 rpm at 80 °C, 1 ml of H_2SO_4 was added dropwise with the help of a dropping funnel. The mixture was refluxed at 80 °C for 24 hours. The solution was precipitated with ethanol. The polymer was filtered and dried at room temperature in a vacuum oven overnight. The chemical structure of the produced polymer was elucidated by ^{1}HNMR and ATR-FTIR.

Encapsulation studies were carried out for rose oil with the polymer whose synthesis was described above. In the encapsulation study, 1 g of stearic acid substituted polyvinyl alcohol macromolecule was dispersed in 50 mL of distilled water, then 4 mL of 1M citric acid was added to the medium. 1 ml of rose oil was slowly added to the reaction vessel and mixed in a magnetic stirrer at 500 rpm for two hours to ensure encapsulation and complete interaction. The precipitate formed was removed from the liquid part, washed several times with distilled water to get rid of the chemicals trapped on the surface and dried in a vacuum oven. The morphological features of the produced capsules were elucidated by scanning electron microscopy (SEM) with Philips XL30 ESEM-FEG/EDAX. The microcapsules and coatings were brought to solid phase with liquid nitrogen, broken and then coated with platinum to prepare for SEM. Coating formulations with synthesized microcapsules were prepared in accordance with the literature. 7.5 grams of cationic starch was dispersed in 92.5 mL of water and stirred at 95 °C until the mixture became transparent. After it became transparent, it was stirred for another 10 minutes to be homogeneous at this temperature, then cooled to room temperature and added into 1 g of the produced microcapsules. The papers used in the coating were conditioned at 25 °C for two days. The coating formulations produced (with and without capsules) were coated on one side of the paper at 0.1 g/m² at room temperature with laboratory type K303 Multicoater (RK Print Coat Instruments Ltd, UK) using Mayer Rod 2 and dried freely. The coating machine speed was selected at 2 m/min and the average coating thickness of the paper coatings was set to 3 µm. Coatings containing cationic starch with and without capsule were examined with an X-Rite eXact handheld spectrophotometer to investigate whether the capsule changed color. The color difference of the coatings is calculated according to the ΔE2000 formula. The surface properties of the obtained coatings were investigated by scanning electron microscope (SEM). Gloss measurements were made with BYK-Gardner GmbH glossmeter with 60° geometry according to ISO 2813:2014.

In order to determine whether the capsules burst during printing and to determine the printability parameters, screen printing was carried out with magenta color screen printing ink with Arus semi-automatic screen printing machine with a 75° squeegee angle, 77 tpc weaving density, 75 shore hardness with doctor characteristics. The gloss measurements were made using the TAPPI T480 om-15 standard using the BYK Gardner gloss device on the prints. Color measurements were determined using an X-Rite eXact spectrophotometer according to the CIE Lab method.

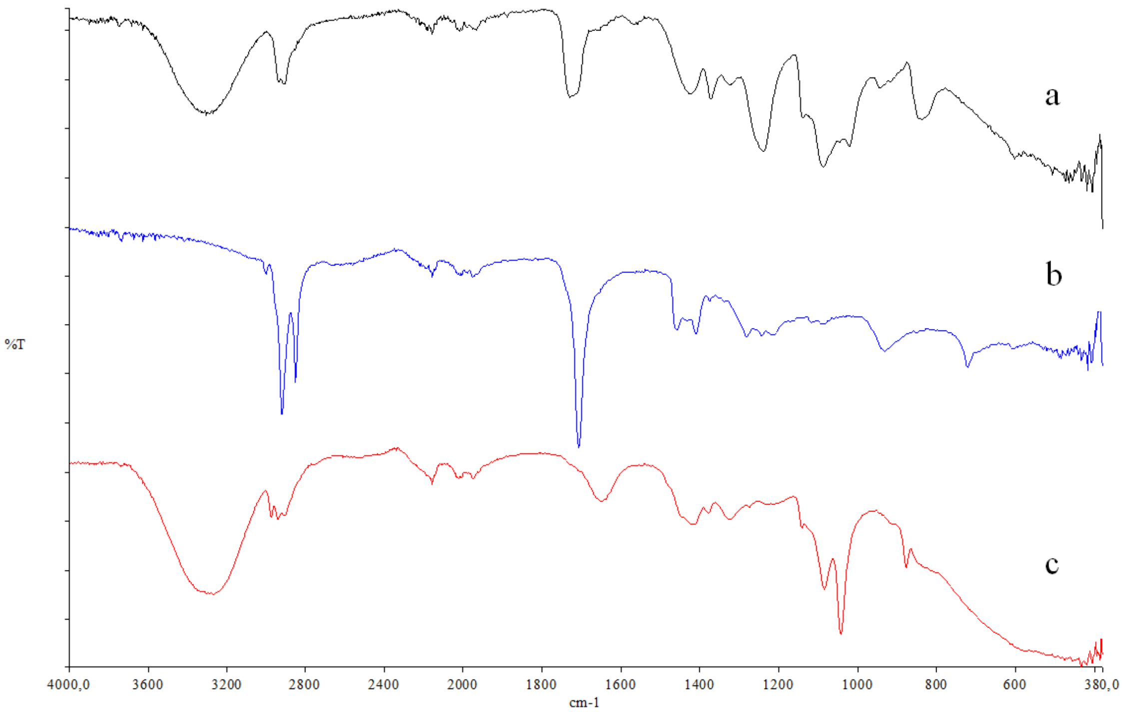
Results

The chemical structure of the synthesized Stearic acid substituted PVA polymer was elucidated by ATR-FTIR (Figure 2) and ^{1}H-NMR (Figure 3). ATR-FTIR and ^{1}H-NMR spectra confirmed the designed structure. When Figure 2.a is examined, characteristic C-H_2 asymmetric alkyl tensile bond vibration is observed for PVA at 2915 cm^{-1}. Also, the vibration of 3307 cm^{-1}-OH and crystalline PVA is 1090 cm^{-1}. In Figure 2.b, 3299 cm^{-1} hydroxyl vibration and 1711 cm^{-1} free carbonyl groups were exposed. Stearic acid substituted polyvinyl alcohol polymer ATR-FTIR spectrum is given in 2.c. The ester vibration clearly visible at 1644 cm^{-1} proves that the reaction has taken place and that the self-protection of the other peaks of stearic acid and PVA does not decompose. Figure 3 shows the characteristic ^{1}H-NMR signals of stearic acid substituted polyvinyl alcohol. The proton on the carbon to which stearic acid is attached was released at 4.69 ppm. In addition, the spectrum shows the proton of the hydroxyl bonded carbon at 3.59 ppm, protons symmetrical to PVA at 1.72 ppm, symmetrical protons on stearic acid at 1.23 ppm, symmetrical protons at the first carbon of stearic acid at 2.25 ppm and at 1.67-0.84 ppm the final protons are clearly visible. The ^{1}H-NMR spectrum proves that the synthesis was carried out successfully. In addition, the ratio of stearic acid PVA was calculated as 11%.

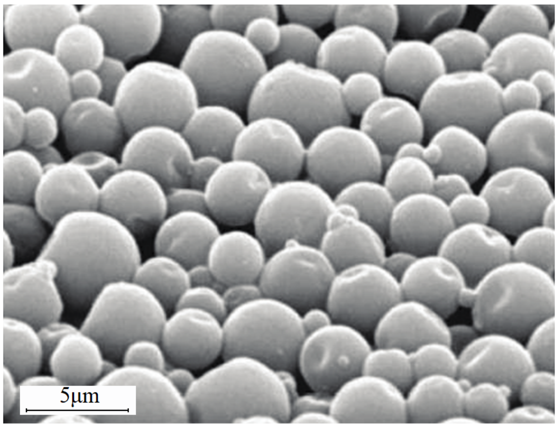


» **Figure 3:** *^{1}H-NMR spectrum of stearic acid substituted polyvinyl alcohol polymer*

Rose oil encapsulation with stearic acid substituted polyvinyl alcohol polymer was successfully performed. The morphological features of the obtained

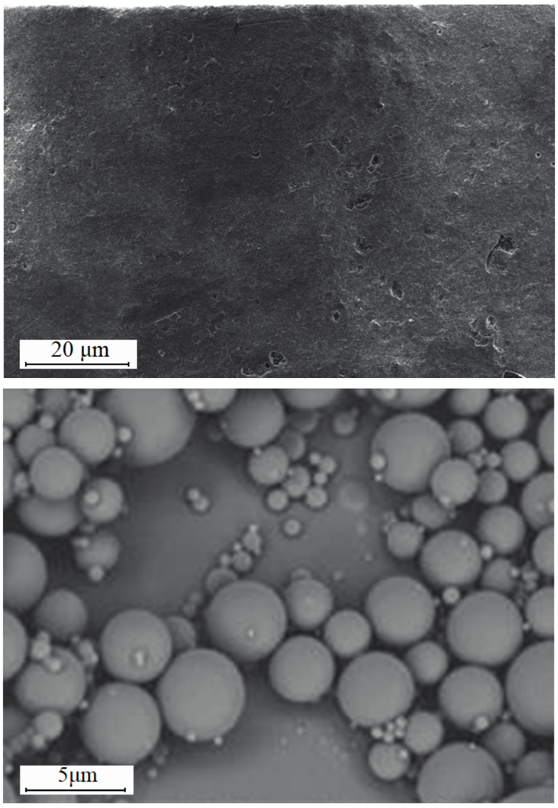


» **Figure 2:** *a) PVA, b) Stearic acid and c) Stearic acid substituted polyvinyl alcohol polymer ATR-FTIR spectrum* capsules were elucidated by SEM (Figure 4). When the obtained SEM image was examined, it was concluded that monodisperse, homogeneously dispersed, 3 µm in size, and not fully spherical capsules with intermittent collapses were obtained.



» **Figure 4:** *SEM image of stearic acid substituted polyvinyl alcohol shell microcapsules with rose oil core material*

Coating formulations with or without synthesized microcapsules were prepared and coated on office papers. The surface properties of the obtained coatings were examined by scanning electron microscopy (SEM) (Figure 5).



» **Figure 5:** *SEM image of stearic acid substituted polyvinyl alcohol shell microcapsules with rose oil core material coated paper*

Stearic acid substituted PVA-rose oil microcapsules were agglomerated in the coating due to Van der Walls interactions between each other and cationic starch, and the distribution was determined to be heterogeneous. However, the capsules could be applied to the surface without any deformation.

The color and gloss properties of the coatings were examined and given in Table 2. When Table 2 was examined, it was determined that microcapsule coated papers were more yellow than normal papers with the change in b values. Also, when the reference value is uncoated paper, the color difference is below ΔE_{00} 3. It's a small change that can't be seen with the naked eye. and in the acceptable color range according to ISO12647. The yellowing in the color of coatings containing microcapsules is due to the color of the oils, which are the internal materials, as well as the chromophore groups in the structure of the polymers. When the gloss values were examined, it was found that it was more glossy than the uncoated paper but less glossy than the cationic starch coated paper. The capsules created a roughness on the surface, which reduced the gloss (Ozcan & Tutak, 2020).

Table 2

Color and gloss properties of uncoated, cationic starch coated, and stearic acid substituted PVA-rose oil capsule coated papers

Properties	Uncoated paper	Cationic starch coated paper	Stearic acid substituted PVA-rose oil capsule coated papers
L	90.87	89.65	90.46
a	2.29	2.19	2.63
b	-8.02	-5.6	-5.07
ΔE_{00}		2.03	2.48
Gloss (TAPPI 60°)	4.5	8.9	8.5

Screen printing was performed on uncoated papers, cationic starch coated paper and microcapsule (with steric acid substituted PVA shell and rose oil core) added coated papers with magenta color screen printing ink. The color and gloss of the obtained prints were measured and given in Table 3.

Table 3

Color and gloss properties of uncoated, cationic starch coated, and stearic acid substituted PVA-rose oil capsule coated papers

Properties	Printed Uncoated paper	Printed cationic starch coated paper	Printed Stearic acid substituted PVA-rose oil capsule coated papers
L	47.68	48.49	47.96
a	74.20	74.53	74.81
b	-3.48	-5.28	-3.97
Gloss (TAPPI 60°)	6.9	16.1	15.2

When the printing results were examined, the biggest change in color of coatings containing cationic starch occurred in the b value. This change in b value shifted the color slightly towards blue. On the other hand, in the capsule coated paper, this blue shift is reduced with the yellowish color of the oil and the capsule, and it is approached to the uncoated paper. When the color differences were examined, it was determined that the ΔE_{00} values of cationic starch coated paper and capsule coated paper were 2 and 0.86, respectively. These values are very small, and the color difference is too indistinct to be perceived by the naked eye. When the gloss results were examined, it was determined that the gloss of the print made on uncoated paper was lower by 2.5 times with the surface treatments. When the gloss results were examined, it was determined that the gloss of the print made on uncoated paper was 2.5 times lower than the surface treated (coated) papers. The results obtained are in line with the unprinted gloss.

Conclusions

In this study, stearic acid substituted polyvinyl alcohol macromolecule was synthesized. When the ATR-FTIR and ^{1}HNMR results were examined, it was determined that the synthesis was successful. Rose oil was successfully encapsulated in weak acidic medium using the related polymer and it was determined that the obtained capsules were monodisperse and 3 micrometers in size. Cationic starch binder paper coating formulations using the obtained capsules were prepared and applied to the paper surface without deformation. It was determined that the colors of the obtained coated papers were very close to the uncoated paper, and the deviation from the color was observed in the b axis due to the yellow color of the oil in general. Screen prints were made on uncoated and coated papers and color and gloss parameters were determined. It was concluded that the color difference decreased to 0.86 in printed capsule-coated papers and the color was so close to each other that it could not be perceived with the eye. As a result, it has been obtained that rose capsules are suitable to produce scented paper.

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