Context-Based Visual Design Language for Shape Generation

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Abstract. Design development is an expensive process and time consuming. A design language system assists design development. The system is highly used to investigate design characteristics in many design studies. The high volume of research interprets it as design elements and principles analysis to deliver consistent visual aesthetics. The absences of meaning and context significantly impact the quality of visual design communication and create design ambiguities. To fulfil the mentioned issues, this research extends harmonised shape grammar (HSG) to develop a context-based visual design language (CVD). The proposed framework provides semantics and pragmatics levels of analysis to bring meaning and context to a visual design communication. Visual communication and language communication share the similarity in fundamental concepts. A context-based visual design language adopts grammatical design and natural language processing approaches to analyse visual communication requirements. Grammatical design provides generative design development when natural language processing analyses levels of language communication. In linguistics, morphological units (morphemes) form a vocabulary. Vocabularies construct a sentence following a grammar structure. A semantically well-formed sentence provides meaning. Meaningful sentences combine pragmatically to achieve a successful communication. In the design aspect, one must speak a language of design. However, speaking does not guarantee a successful communication. This research aims at defining a framework to create a set of meaningful visual design language in order to achieve a visual communication correspondingly to the way natural language can in linguistics.

Keywords: Visual design language · Harmonised shape grammar · Natural language processing

1 Introduction

Language is a system of communication consisting of sound, words, and grammar [1]. It can be used to communicate by people in a particular country or a specific group of individuals and tasks. Learning one language requires an understanding in its meaning and structure [2]. Linguistics is a scientific study of language and its structure [3]. The study includes morphology, syntax, phonetics, and semantics [4, 5]. Morphology studies

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the forms of words. Syntax deals with a language structure and phrasing. Phonetics classifies speech sounds. Semantics concerns meaning [6]. In a natural language processing (NLP), the study aims at using artificial intelligence (AI) to understand and be able to communicate between computers and humans [7]. The study develops knowledge in both natural language and AI fields [8]. In the natural language aspect, it includes lexicon, syntax, semantics, and pragmatics studies. Lexicon deals with vocabulary when pragmatics deals with context. Design language refers to a scheme or a style that guides the design. The aim is to create a consistency in design. It focuses on design elements and principles by describing aspects of design such as shapes, colour schemes, materials, patterns, and layouts [9]. It is used in many design processes such as product design, architectural design, and industrial design [10].

To communicate in one language, one must understand its vocabularies and grammar. Design can speak similarly to the way natural language does. The cognitive abilities that people apply in order to speak and understand a language are similar to those applied to other cognitive tasks, such as visual perception or reasoning activity [11]. To communicate in one design, the design must carry a form of coherence structure. A design language speaks with design elements and principles to create a consistent visual aesthetic [12]. However, the absences in design meaning and design context bring serious issues in communication ambiguities. A meaningful design requires further analysis in semantics and pragmatics levels. The design vocabulary and structure must be defined in morphology, lexicon, and syntax levels to achieve a successful communication.

This research aims at adopting knowledge of linguistic concepts, natural language processing, and design language system to provide a visual design framework namely a context-based visual design language. The proposed framework aims at creating a consistency in design and visual communication the way people communicate in natural language. The proposed framework consists of five levels of analysis including shape morphology, design lexicon, design syntax, design semantics, and design pragmatics.

2 Overview of Natural Language Processing and Design Language

This section describes the uses of linguistics and visual design that are adopted in this research by following the fundamental concept to identify a context-based visual design language.

2.1 Natural Language Processing

Natural language processing is a computational linguistics that studies the engineering of computational models [13]. It aims at creating a cognitive process to understand human language. Natural language consists of emotional expressions and spoken languages [14]. People use natural language to communicate to each other. Natural language processing, on the other hand, is a knowledge-based approach to analyse human language to communicate between humans and machines [5]. Natural language processing involves levels of analysis including morphology, lexicon, syntax, semantics, and pragmatics [4, 5]. The first level of analysis is morphology which focuses on word morphemes. A word is constructed from a series of morphemes so-called morphological units in terms of a

word structure. The second level of analysis is lexicon which concerns word meaning. For example, this word is a noun or a verb and what meaning it is carried. The third level of analysis is syntax which determines the grammar structure of a language. Grammar is a structural dependency relationship used to put words together syntactically to form a sentence [15]. The fourth level of analysis is semantics which considers the meaning of a sentence. The interactions among word-level meaning have to be considered to avoid ambiguities in language [16]. The fifth level of analysis is pragmatics which focuses on the overall context of conversations. A sentence can carry more than one meaning depending on its surrounding sentences. In order to define a correct meaning, a completed context of the communication must be considered together. Ambiguities in language processing can be found at many levels of language analysis and types of communication [17]. The overall context is required to be defined.

2.2 Design Language System

Design is defined as the process of creating new structures characterised by new parameters, aimed at satisfying specific requirements [18]. Design elements and design principles are the fundamental structure of design. Design elements consist of point or mark, line, shape, form, space, colour, and texture [19]. The artist uses these basic elements as design building blocks. Design principles consist of balance, proportion, emphasis, movement, pattern, repetition, rhythm, variety, harmony, and unity [20]. These principles are used as laws and guidelines for design considerations. Design elements are combined to create components when design principles are applied to create design direction [21]. It is similar to the way music is composed. Notes and tones are components put together to identify a form of patterns. These patterns follow a constructive direction to create harmony. Design language is a design scheme describing choices of design aspects [22]. The aim is to achieve aesthetics and consistency in the design development the way harmony is achieved in music composition. A language of design must speak through design characteristics. By applying design elements and principles, any design can speak. However, the absences in design meaning and context lead significantly to design ambiguities. A successful visual communication must be meaningful. To communicate effectively, two more levels of analysis are required; design semantics and design pragmatics. Speaking a design language meaningfully requires design morphology at semantics level and design context at the pragmatics level.

2.3 Perception in Design

Design aesthetics can be quite a subjective issue. This research applies a processing of human perception development as a guideline to analyse the human perception in design. A design aesthetics is appreciated when humans experience an art form [23]. There are three levels of processing including visceral, behavioural, and reflective [24]. The first level of analysis is visceral which focuses on the human first impression of design appearance. It is a reaction toward the look of an object. The second level of analysis is behavioural which concerns design function. Human brain processes the passing pf the point on how it looks to how it works and the information it carries [25]. Function that is suitable with user requirements raises the level of user appreciation

toward the design. The third level of analysis is reflective which involves the personal satisfaction. Each person can have a different feeling toward one design. The feeling depends on that person's self-image, self-satisfaction, and memories [24]. In order to achieve a satisfaction perception in design, the three levels of analysis must be fulfilled. To accomplish a meaningful and consistent visual aesthetics, the design must not only speak its design language but must communicate without design ambiguities and clarifies its morphology and functionality through the design meaning and context.

3 Context-Based Visual Design Language

This research proposes a context-based visual design language (CVD) to provide a successful design communication. The proposed framework adopts the approaches of natural language processing and design language system by extending three levels of analysis; shape morphology, design semantics, and design pragmatics. Natural language processing is a subarea of research in linguistics. It concerns analysing and studying the natural language data. Design language system uses design principles to create a design scheme. This design scheme can be used as a guideline to create design style. Grammatical design generates a design using design syntax and semantics without any concerns of design morphology, contexts, and ambiguities. A context-based visual design language consists of five levels of analysis; shape morphology, design lexicon, design syntax, design semantics, and design pragmatics. They are interpreted as compatible to semantics and pragmatics in natural language. The extensions of design semantics and design pragmatics provide meaningful and contextual design outcomes. They also prevent design ambiguities in visual communication (Fig. 1).

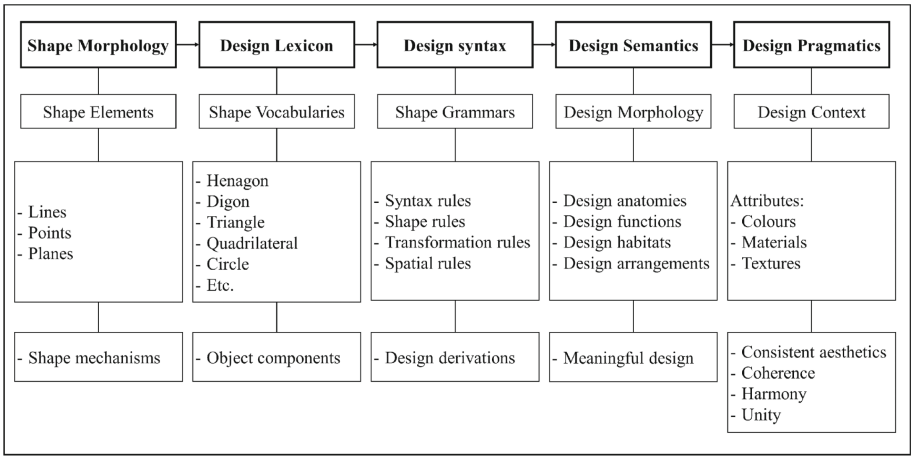

Fig. 1. A figure shows a context-based visual design language model. There are five levels of analysis starting from left to right. Shape morphology creates shape vocabularies. Design syntax brings design structure to generate design derivations. Design semantics develops those derivations with design morphology consideration. Design pragmatics provides context of design.

3.1 Shape Morphology Level of Analysis

In linguistics, morphology focuses on word morphemes. In terms of a word structure, a word is constructed from a series of morphemes called morphological units. Alphabet is the smallest component of a word. Alphabets build a set of morphemes conceptually the way a series of points build a line in design. A combination of lines creates a shape component the way words are created with a group of morphemes.

In a context-based visual design language, shape morphology investigates design elements. Design elements analyse shape componentry. Shape componentry is a fundamental component of shape. It consists of point(s), line(s), and plane(s). A point is the smallest unit of shape componentry. Multiple points form a single line. Connecting multiple lines together is to create a plane. Any shape or form must consist of at least one of these components. A set of rules can be applied to design elements in order to create a set of shape morphologies. The created shape morphologies can be used to develop a shape vocabulary at the next level of a design analysis. To define consistent morpheme rules is the key to achieve a set of useful shape components. The developed shape components can create a design coherence. It is similar to morphology rules in natural language. One can apply a language morphology rule as a guideline to create a number of new words using the same rule. This is a significant step forward to start a design development process where new shape elements are difficult to create with consistency and coherence in a visual communication. Shape morphology works as a design assistance providing such a guideline to generate new shape elements (Fig. 2).

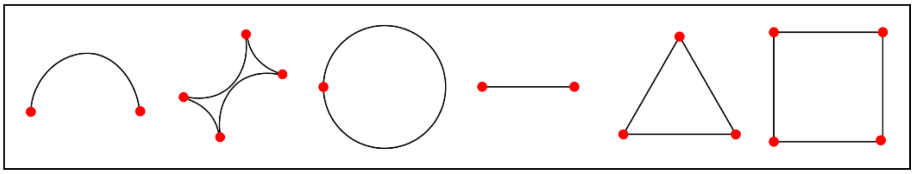

Fig. 2. A figure shows shape morphologies, from left to right; a parabola curve (1-side-2-vertex), a hyperbola shape (4-side-4-vertex), a henagon (1-side-1-vertex), a line (1-side-2-vertex), a triangle (3-side-3-vertex), and a quadrilateral (4-side-4-vertex). Morphology level operates design elements mathematically to create shape components.

3.2 Design Lexicon Level of Analysis

In linguistics, lexicon concerns the meaning of words and their part(s) of speech. Lexicon determines types of words such as a noun and a verb. Each type plays their own roles in language structure. Ambiguities occur when a word has more than one meaning. For example, a word "bar" carries multiple meanings in both noun or verb forms. This issue must be dealt with at the further analysis levels; syntax, semantics, and pragmatics levels.

In a context-based visual design language, design lexicon includes design vocabulary analysis. Design vocabulary is a container of shapes. It consists of 2D shapes and 3D forms developed from the same shape morphology rule(s). Polygons can be created

by combining a set of vertices (points) and sides (lines) together geometrically. Polygon types are divided by their specific number of sides. For example, a 1-side-1-vertex component forms a henagon; a 2-side-2-vertex component forms a digon; a 3-side-3-vertex component forms a triangle; a 4-side-4-vertex component forms a quadrilateral, a 5-side-5-vertex forms a pentagon, and 4-side-4-vertex curved lines form a hyperbola shape. Design lexicon creates shape vocabularies from shape morphology. Morphologically well-formed shapes themselves can be meaningless or meaningful depending on the design purpose. Sets of selected shape morphologies are stored at the morphology level. At lexicon level, those shape morphologies are developed in such a way to create a shape vocabulary (a lexically well-formed shape) to use as design materials. By applying a set of rules repeatedly, a number of new shape vocabularies can be achieved. All shape members are developed sharing the same design direction (Fig. 3).

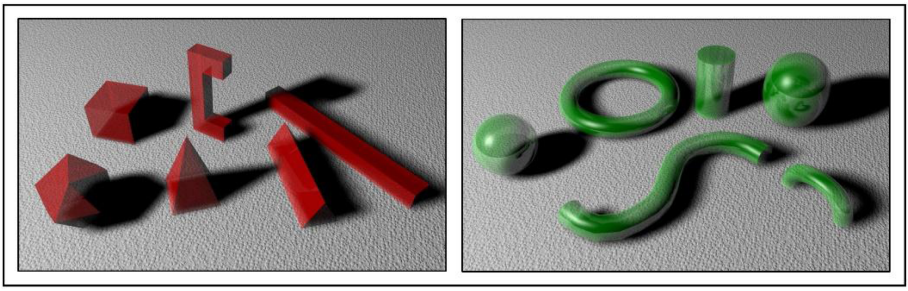

Fig. 3. A figure shows two sets of shape vocabularies. The left picture shows a set that is developed by a quadrilateral, 4-side-4-vertex, shape morphology. The right picture shows a set that is developed by a henagon, 1-side-1-vertex shape morphology. Lexicon rules analyse the two shape elements to generate sets of shape vocabularies.

3.3 Design Syntax Level of Analysis

In linguistics, to form a sentence, a type of language structure is required. Grammar is a set of rules to construct a sentence. Syntax level of analysis determines word types; noun phrase and verb phrase. In general, a sentence is created by applying grammar rules to these word types. Language grammar uses these word types to create a sentence following the defined sentence structures. A syntactically well-formed sentence can be used for communication without any guarantee of language ambiguities.

In a context-based visual design language, design syntax provides a grammar of design. Design grammar defines a shape rule which is similar to the grammar rule in natural language. Grammatical design is used in many design fields such as architectural, engineering, and product designs. Shape rule offers a structure to develop design vocabulary following one direction. It consists of spatial relation rules and transformation rules. The rules develop syntactically well-formed design choices. By applying a shape rule repeatedly to one shape vocabulary, a number of design derivations are generated. All design derivations in one particular set share the same conceptual design

structure. Harmony and unity in shape development are achieved as a result. This level adopts a concept of grammatical design approach by developing syntax rules. A generated shape, called design derivation, is created by applying a set of well-formed syntax rules to shape vocabularies. Defining effective but simple and repeatable syntax rules is an important factor. It requires an in-depth understanding in mathematics and shape geometry. A grammatical design generates random derivations but still lacks meaningful structure to develop those vocabularies. A context-based visual design language tackles the mentioned issue by applying another two levels of analysis (Fig. 4).

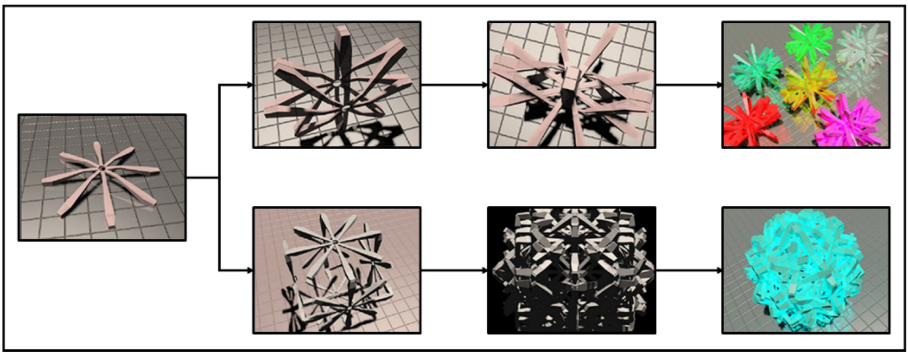

Fig. 4. A figure shows design developments at the syntax level. A quadrilateral shape is developed to form a fan shape at lexicon level. Multiple syntax rules are applied to the fan shape to generate two sets of design. Different spatial and transformation rules, such as rotation and translation, are applied repeatedly. A number of complex design derivations are generated as the result.

3.4 Design Semantics Level of Analysis

In linguistics, semantics considers the meaning of a sentence. Words that have multiple meanings lead to language ambiguities. The interactions among word-level meanings have to be considered to avoid ambiguities in language. To understand which is the correct meaning, one must understand the overall denotation of each word individually and as a sentence. A meaningful sentence must be clear and meaningful without any language ambiguities.

In a context-based visual design language, design semantics concerns design morphology. The term morphology is interpreted differently to the term used in linguistics. Design morphology deals with meaning of design. A grammar-based design language does not guarantee the design to be meaningful. The same problem occurs in both design and linguistics studies. For example, in linguistics, a sentence “hat eats table” is grammatically correct. However, it is not semantically well-formed because the sentence makes no sense and meaningless. Design syntax creates random design derivations which mostly lead to an ambiguity in design. Design semantics controls design development by applying design morphology to make it meaningful. The design morphology consists of design anatomy, design function, design environment, and design arrangement. Design

anatomy defines bodily structure of objects or character requirements. For example, a car anatomy requires the car body, seats, steering wheels, control system, engine, and wheels. Design function concerns activities and purposes of each part of that anatomy. For example, a car body is to hold car components together; driver and passengers' seats are to give a driver and passengers spaces to operate inside; a steering wheel and controls are to govern direction and movement; a car engine is to provide its power; and wheels are to mobilise a car when rotated simultaneously. Design environment analyses object surroundings that affect the behaviours of design. For example, a terrestrial, aquatic, or atmospheric environments affect design approach of the car. Design arrangement considers the design components composition. For example, wheels should be attached one part to the car body and one part touches the ground; driver seat should be next to the steering wheel, and seats should be inside the car body. Design derivations are developed to follow design morphology to achieve meaningful design which significantly increases design quality and reduces the time-consuming issue (Fig. 5).

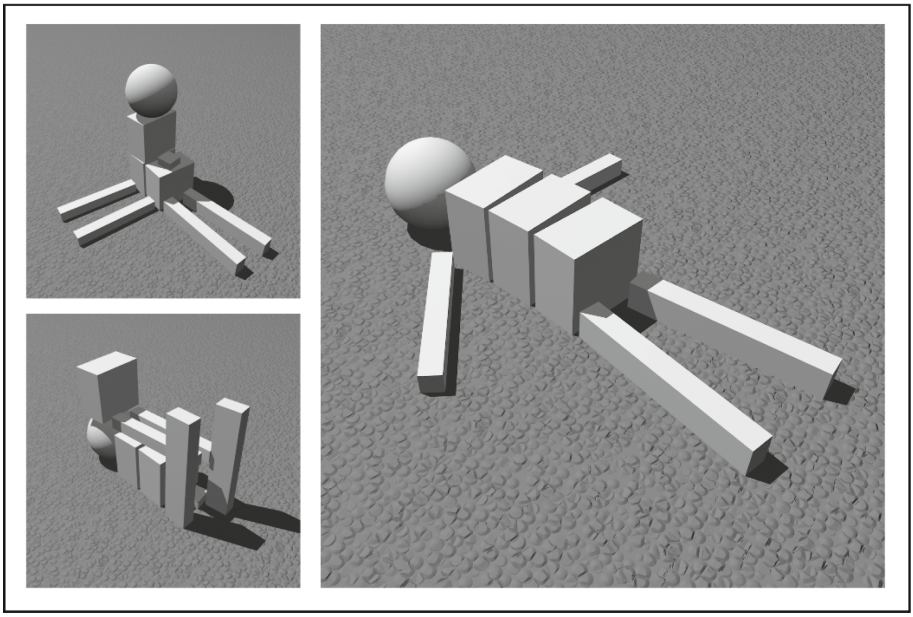

Fig. 5. A figure shows three sets of design developments. Each set has exactly the same derivation structure. Applying different syntax rules creates diversity in design. The two on the left are generated by syntax rules without design semantics. The one on the right is developed with design semantics consideration. Providing design morphology, design anatomy, function, environment, and arrangement, a meaningful humanoid character is created.

3.5 Design Pragmatics Level of Analysis

In linguistics, a conversation consists of a series of sentences. In order to avoid language ambiguities, it is not an individual sentence but the overall context of a conversation must

be considered. All sentences must communicate with the same purpose and direction. It is similar to music composing. A sequence of notes and tunes are combined to create melody harmoniously. A level of satisfaction is achieved when listening to the whole composition as a piece of music not as an individual note and tone.

In a context-based visual design language, design pragmatics provides the context of design. Design semantics focuses on the meaning of an individual design. Design pragmatics considers the context of a set of design as a whole. An absence of context consideration leads significantly to an inefficient visual communication. At the first four levels of design analysis, an individual design speaks its own language separately. Design pragmatics aims at offering contexts to those designs in a specific direction harmoniously. Design context consists of design attributes; colours, materials, and textures. Design attributes define characteristics of a design surface in terms of a colour scheme. This colour scheme is applied to create a set of materials and textures that share the same characteristic and behaviour. These attributes are applied to all objects to create a consistent visual aesthetic. This analysis can be applied for both 2D and 3D designs. All design objects are developed to share the same design morphology and context. In the design perception, each shape vocabulary has its own meaning. For example, round shape gives friendly and unstable feelings; a triangle shape gives dangerous and dynamic feelings; a square shape gives static and stable feelings; and a straight horizontal line makes people feel calm and stable. A context-based visual design language analyses the design perception to bring meaning to compound shapes. Design syntax creates a set of derivations that share the same design characteristics. Design semantics combines them in such a way that is meaningful. Design pragmatics provides the overall context as a design theme. Harmony and unity in design can be achieved when all designs in one set speak in the same design as morphology and context.

4 Implementation of the Framework

The proposed framework can be applied to generate many types of design. To implement the framework, this research uses game environment design as a case study. The aim is to generate a set of game assets, a terrestrial habitat game environment. All generated assets must carry consistent visual aesthetics and design coherence. This design development process follows the five levels of analysis of context-based visual design language; shape morphology, design lexicon, design syntax, design semantics, and design pragmatics.

The process begins with defining shape morphology. A henagon (1-side-1-vertex) and a curve line (1-side-2-vertex) are used as shape elements. Henagons and Curved lines are basic shape elements found in many organic forms. They give the feelings of smoothness and movement. Shape morphology defines these shape elements to be developed as shape vocabularies.

At a design lexicon level, the spatial and transformation rules are applied to the defined shape vocabularies. Rotation rules are applied to henagon to create a sphere. Translation rules are applied to curved line to move 360º along henagon radios to create a cylinder.

At a design syntax level, syntax rules, emergent rules, spatial rules, and transformation rules are applied to develop those shape vocabularies using shape algebra. The rules

define a henagon-sphere as a starting vocabulary. A curved-line-cylinder emerges from the starting vocabulary to any direction to form a new shape vocabulary. The rules are reapplied limitlessly and are terminated when the design derivation meets the level of satisfaction.

At a design semantics level, the syntax shapes are further developed to create design morphology which consists of design anatomy, design function, design environment, and design arrangement. This process divides design morphology into three specific sub-morphologies including building, character, and vehicle. The developments of each sub-morphology are as follows;

1) The building anatomy requires a building to have a building body and a roof. The building function creates interior spaces, doors, and windows. The interior spaces are for habitation purposes. The door is to connect an interior space with outside spaces. The windows for air ventilation provide interior lighting. The building environment defines surrounding factors that affect building morphology. In this case, the morphology focuses on a terrestrial habitat. The building arrangement deals with placing building components in the right order. For example, the roof is on top of the building body; the door is placed on a ground level; and the windows are attached to the building body not the roof. This implementation uses henagon-spheres to offer an interior space. Emerged curve-line-cylinder shapes are used to develop exterior structures such as roofs and terraces (Fig. 6).
2) Character anatomy requires head, body, and limbs to be created. A henagon-sphere shape is used to create the head part with emerging curved-line-cylinders as body and limbs. The head function is to carry facial components. Each component carries its own specific function; eye to see, ear to hear, or nose to breathe. The body is for limbs to be attached to. The upper limbs functions are to grasp and hold, and the lower limbs are for standing and moving. Terrestrial morphology is required to fulfil the character environment. Character arrangement follows the function and environment. Head and limbs are attached to the body. Upper and lower limbs must be placed according to their functions. Upper limbs are attached to the upper body. Lower limbs are placed at the bottom to carry the body and to move.
3) Vehicle anatomy requires vehicle body and wheels. A henagon-sphere is used as a starting vocabulary. Curved-line-cylinders emerge from this henagon-sphere to create the vehicle of the body and wheels. Vehicle function requires driving or riding spaces. Vehicle handles are created to fulfil control system function. A vehicle requires a mechanism to move effectively. Instead of wheels, this implementation mimics caterpillar movement functions to suit the terrestrial environment. Vehicle arrangement places caterpillar legs at the bottommost position and driving or riding spaces on the vehicle body next to its control system.

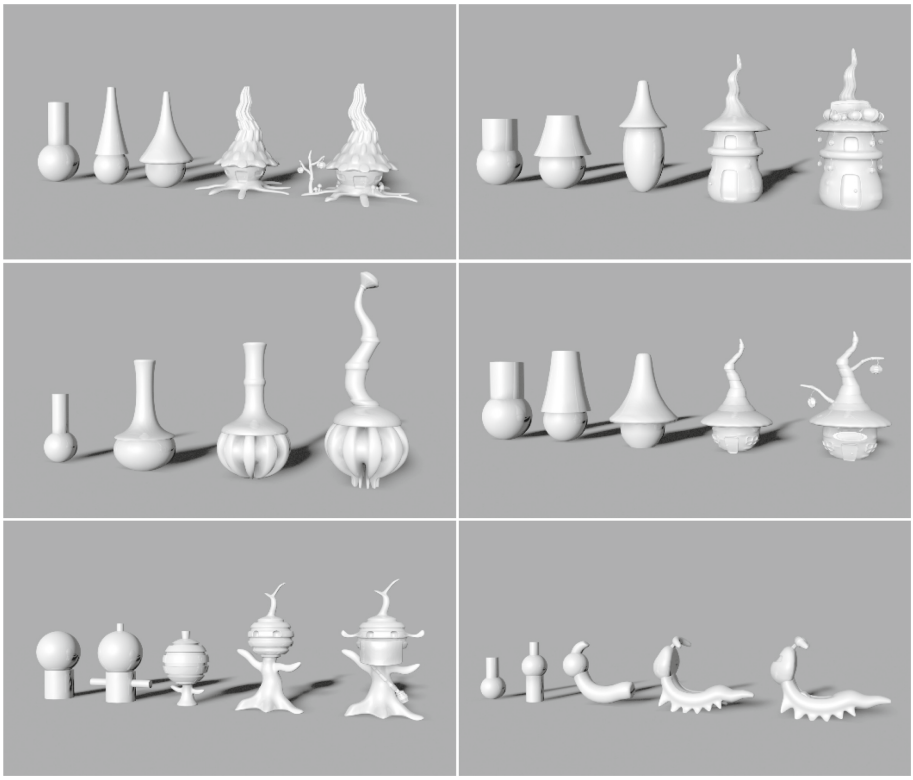

Fig. 6. A figure shows design developments of buildings, character, and vehicle. The process starts, from left to right, with two shape vocabularies; a henagon-sphere and a curved-line-cylinder. Syntax, semantics, and pragmatics rules are applied to develop the design with consideration of design morphology and context.

At the design pragmatics level, the contexts of design are applied. The three sub-morphologies; building, character, and vehicle, are developed individually at the previous four levels. The shape morphology, design lexicon, design syntax, design semantics processes develop designs that share identical forms. This level interprets design contexts through design attributes. The design context provides a design theme to achieve a consistent visual aesthetic, coherence, harmony, and unity in design. This implementation focuses on colour and material. Black and white based colours are applied to create a grayscale colour scheme. A low specular value is used to create environment materials when a high specular value is applied to asset materials (Fig. 7).

Fig. 7. A figure shows the developed models; buildings, characters, and vehicles, at pragmatics level of analysis. All assets are expressed with the same conceptual morphology and context of designs.

5 Conclusions and Future Work

The absences of design meanings and contexts in design lead significantly to ambiguities in visual design communication. This research proposes a Context-based visual design language to tackle the mentioned issues. Design meanings and contexts are achieved through semantics and pragmatics levels of analysis. The proposed framework extends harmonised shape grammar to provide an alternative successful visual communication framework. The proposed framework adopts natural language processing and design language system approaches. A context-based visual design language consists of five levels of analysis; shape morphology, design lexicon, design syntax, design semantics, and design pragmatics. Shape morphology deals with defining shape element; point, line, and plane. Design lexicon offers transformation, and spatial rules to create shape vocabulary from shape morphology. Design syntax analyses the syntax rules to develop shape vocabulary following its shape grammar structure. Design semantics delivers meaningful shapes following the design morphology; design anatomy, function, environment, and arrangement. Design pragmatics considers the overall context of design to communicate in the same representative determination and to avoid ambiguities in design. This research applies the context-based design language to produce the game environment design as a case study to implement the framework. The result shows a significant improvement in design quality and reduction of time-consuming issues. A set of game environment design is generated as a case study for the research implementation. The generated assets consist of three types of design; building, character, and vehicle. The design results are checked up against design elements and design principles to evaluate the quality of design. The design analysis follows design criteria of harmonised shape grammar and the three levels of design perception which provides a platform to

evaluate design qualities. The evaluation yields a successful and harmonious result with a very little time consuming in term of design development. The context-based visual design language can be used as an alternative design development approach when a huge number of designs is required with a time limitation.

This research addresses serious issues in the absences of design meaning and context. The proposed framework introduces an alternative generative design development framework. This research focuses on visual design and its development. There are a number of important areas for further improvement. Firstly, this framework has not focused on motion graphics and movements. Directions, velocities, patterns, and behaviours of a motion provide their meanings. These factors significantly affect design decisions and should be considered. Secondly, the semantics and pragmatics rules require an in-depth understanding in 2D and 3D shape algebra, and geometry transformation. In order to operate the rules effectively, a guideline in semantics and pragmatics rules are advised to be analysed and studied further.

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