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# Development of a Procedure for Camouflage Pattern Design

**Abstract**
*Today, camouflage uniforms are an indispensable part of military equipment and serve not only as a means of disguising an object in a certain environment but also as a national symbol. Since battlefields and areas of international conflicts also take place in urban environments, the need to design urban camouflage is all the greater. The purpose of the research was to develop a procedure to create a set of camouflage patterns for the urban environment. The experimental part included the selection and processing of digital images of representative urban environments. Image processing simplified the digital photos by changing them into surface elements and contours, which helped us to extract representative shapes and sequences. Afterwards three methods for pattern design including the random and planned composition of shapes and sequences were developed and analysed. The procedures for pattern design included compositional and pictorial analyses of simplified digital images, principles of fractal sequences, a theory of the psychophysical comprehension of shapes and sequences, and knowledge about the visual and optical effects of shapes and repeats. The result of the research was the definition of an optimal procedure for digital camouflage pattern design, which was also confirmed by the Slovenian Ministry of Defence and Armed Forces.*

**Key words:** *pattern, camouflage, design procedure, shapes, contours.*

## Introduction

National identity is one of the most important factors that enable national existence and its differentiation from others. The development of national identity is possible with the help of history, language, currency, and national symbols (i.e. flags, coats-of-arms, uniforms of representative organs of a nation and country). Although a national armed force is not obligatory for the existence and development of the nation, it is recommended because of collaboration at an international level.

A military uniform is an indispensable element of military identity and its existence. We can hardly imagine military uniforms without a camouflage pattern. Historical review, however, shows that patterns were introduced as a part of the uniform only in 1914, when the French army tested military equipment with a colourful geometrical pattern, which was similar to the forms and colours of the environment and, consequently, had a camouflage effect. Before WW1, military uniforms were one-, two- or three-colour clothes, mostly black, white and red in colour (French and British Army) [1 - 3].

In the beginning, the design of camouflage patterns was in the hands of artists and designers, who, during the decades of the twentieth century, improved their work in strong collaboration with the army [4, 5]. An important breakthrough occurred in the late 1970s, when development in the fields of science and computer technology also penetrated the realm of camouflage. In that period Timothy R. O'Neill introduced so called digital camouflage, which caught the attention of armed forces all over the world. Science was involved in the art and technology of camouflage because of knowledge about the biophysics of the human visual system, perception and abilities of detection. The first experiments included two level textures (raster) which enabled a camouflage effect at two different observing distances [6, 7]. Developments continued in the direction of the use of patterns with a pixelate visual appearance. The procedure for designing a digital camouflage pattern can be generally described as computer aided processing of digital photos acquired in a specific environment. Processing involves (patented) mathematical algorithms and transformations of digital image data. Consequently, the purpose of camouflage pattern is to disrupt the form of a target object (i.e. man, vehicle, building) and make a target unrecognisable in a specific environment [8 - 11].

USA and Canada have been making the biggest progress in the development and introduction of innovations in the field of camouflage patterns and consequently dictate trends in camouflage technology and art. In practice, the influence of these two countries has brought about visual similarities and even identicalness between the military uniforms of solders from different countries in known world battle areas (the Balkans, Near and Far East countries). Therefore the different countries that collaborate in international military unions (i.e. NATO) have become involved in the development of their own representative military uniform for different environments (wood, desert, snow, city). Representative national military uniforms would induce a strengthened military identity in each nation.

The Department of Textiles at the Faculty of Natural Sciences and Engineering (University of Ljubljana, Slovenia) was chosen to collaborate in the objective project "Knowledge for Safety and Peace 2006-2010". The basic goal of the project was the production of a multi-functional protective textile for military uniforms. The target environment of the project was the Slovenian urban environment, but with the possibility of developing the pattern for use in other environments. The purpose of the research was the development of new procedures for urban camouflage pattern design that would differ from computer generated digital patterns in the sense that a new pattern would keep camouflage properties in different urban surroundings or backgrounds, i.e. old towns, industrial and shopping centres, and modern areas. The research presented in this paper was only one part of the project. The project also included other parallel extensive researches, the experimental part of which comprised a definition of representative urban colours and procedures for achieving camouflage effects also in near IR fields of electromagnetic radiation [12].

## Theoretical part

### Psychophysical properties of the human visual system

The human visual system is not only connected with human eyes, visual nerves and neurological centres in the brain but also with the psychology of perception and psychophysics. Psychophysics is a subfield of psychology that studies physical stimuli and perception actuated while our sense organs (sense of sight, hearing and smell) are active. Consequently, detection is not only physically (optical) seeing an object but also includes other parallel processes which present a relation between stimuli and the human senses while the stimuli is in progress. During the detection of visual data (e.g. the basic signal that is analysed in camouflage art and technology), a sequence of psychical activities takes place: visual acuity, temporal resolution, light and dark adaptation, and the perception of colour, space and depth [13].

The methods and principles involved in psychophysical processes are used for the definition of the threshold of the eye. For an ideal observer, the threshold of the eye is the point at which stimuli is still perceived and/or is not perceived any more.

The psychophysical mechanism of the human visual system is very complex as it includes all the parameters mentioned above. The research, however, was focused mostly on visual acuity, since the camouflage pattern and its shapes should be unrecognisable at predefined observing distances [14, 15].

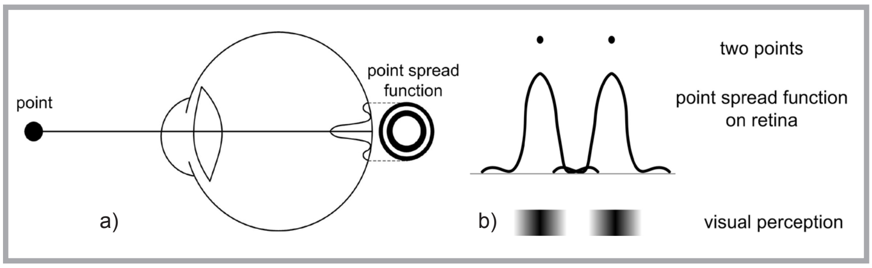


***Figure 1.*** *Point spread function of a point stimulus (a) and visual perception (b).*

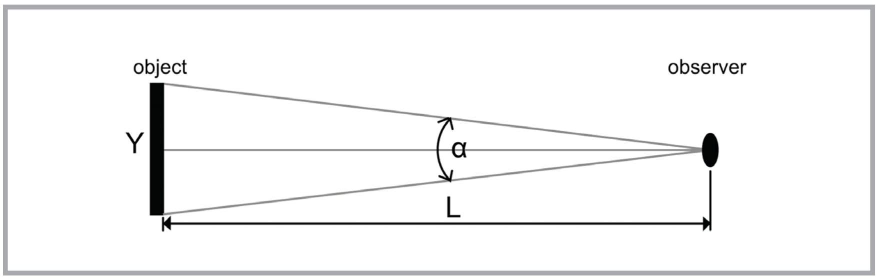


***Figure 2.*** *Visual acuity and recognition of an object at distance L.*

### Visual acuity

Visual acuity is the ability to differ visual signals of different strength in the sense of surface and volume perception (also to differ 2D and 3D objects from the surroundings). Visual acuity is also a measure of how fine an observer can resolve details to maximum contrast [16]. Visual acuity depends on many factors, among which more pronounced are the following: physical phenomena in the eye (light refraction and diffraction), the density of photoreceptors in the retina, illumination, the openness of the pupil at the time of illumination of an object, contrast between an object and its background, the area in the retina that is stimulated, and the movement of the eye. The human eye recognises a small element or point as stimulus, when, by viewing an object, visual stimuli in the retina is strong enough. By detection a point is not directly represented as point stimulus in the retina but as a point spread function, as is presented in ***Figure1.a*** [15].

The point spread function directly depends on the wave length $\lambda$ in nm and diameter of the pupil $d$ in nm. The recognition of two separate points is, according to the Rayleigh criteria shown in ***Figure 1.b***, possible only if the distance between points is equal to the length of the point spread function; their angular resolution $\alpha_S$ is given by Equation (1). When two point elements are inside this distance, they are perceived as a single element.

$$\alpha_S = 1.22\ \lambda / d \tag{1}$$

The art of camouflage is centred around detection at longer distances from the target. Here the visual acuity of a standard (normal) observer is 1′ (arc minute), given by Equation (2), where the dimension of the target object is $Y$ in cm and distance between the object and observer is $L$ in cm [15]. The detection of an object at longer distances is presented in ***Figure 2***.

$$\alpha = Y / L \tag{2}$$

Psychometrics, i.e. methods for the evaluation of visual acuity include the tests presented below [*15*]:

- perception of a target – task requires perception of the presence or absence of a target but not the recognition of target details,
- recognition of a target – task requires the recognition and naming of a target,
- threshold of the resolution – defined as the smallest angular distance at which an observer can distinguish the distance between elements in the pattern.

Visual acuity depends on the contrast sensitivity. Clinical analyses of visual acuity are performed in high contrast, with black lines on a white background.

However, in the real world objects do not contrast so much with the surroundings, which has to be taken into consideration during psychometric experiments.

### Theoretical fundamentals of pattern composition

Many parameters should be mentioned as being of great importance in pattern compositions, most of which derive from the theory of aesthetics and art theory [17, 18]. In this study, however, only two technical parameters will be discussed: the basics of Gestalt psychology and fractal geometry.

### Gestalt psychology and visual perception

In camouflage patterns there are valid principles of the perceptual organisation of elements which have to be considered when designing a composition of shapes in aesthetic sequences with additional technical value. Depending on the dimensions of shapes, their form, the distance between them and their organisation, specific relations are developed between shapes which influence the final perception of the pattern.

Gestalt psychology is based on the fact that the relation between two or more shapes and the composition of shapes at the surface level gains a new value of content in comparison with a single shape. This value derives from psychological processes actuated by visual perception. Gestalt psychology is also founded on the fundamentals and universal principles of perceptual organization, as are the following [19]:

- *Law of proximity* – elements lying close to each other in the pattern are visually connected,
- *Law of similarity* – similar elements are visually connected,
- *Law of continuity* – elements which continue in the same direction or certain pattern, are connected together as a part of the whole,
- *Law of closure* – interpretation of groups of elements that create close forms, which have advances prior to open groups of elements,
- *Law of smallness* – our perception of small surface areas has a tendency to be a figure on a bigger background,
- *Law of symmetry* – our perception of symmetrical surface areas has a tendency to be a figure on a non-symmetrical background [13, 15].

### Fractal geometry

Fractals are self-similar functions connected with the theory of chaos. In geometrical terms fractals are self-similar and fragmentated shapes on different levels [20, 21]. Because of the obvious presence of these mathematical functions in nature, experts and scientists apply them in digital camouflage patterns, as is presented in ***Figure 3***, showing the camouflage pattern of the United Dynamic Corps. The pattern of leaf woods was developed using proprietary graphic techniques known as Camouflage Designated Enhanced Fractal Geometry (C2G) [22].

The patterns presented in this paper were not generated by mathematical functions nor by self-similarity functions. As already mentioned in the introduction, the purpose of this research was to design a universal pattern for different urban surroundings, hence the use of algorithms was not included. Nevertheless, some visual aspects and principles of fractal geometry were considered, such as the fractal positions of elements on a surface, as well as the self-similarity and division of the whole into small similar particles.

### Camouflage and detection of a target

The basic meaning of detection is the visual separation of an object from the surroundings (background) or recognition of an object in an environment. The purpose of camouflage is to disrupt the form or/and shape of military (target) objects to make them unrecognisable in an environment. It can also be said that camouflage causes the concealment of an object so that it is visually similar to the surroundings. Military objects, i.e. humans, vehicles and buildings are, as 2D and 3D forms, different from the natural (wood, snow and desert terrains) and artificially organised systems (various forms of urban environments) in which they usually act, which is why their form has to be disrupted and visually approximated to the forms of the environment.

Camouflage is a phenomenon that predominantly involves the human visual system; however, due to the complexity of perception, other senses also remain active. The camouflage of an object depends on many factors occurring parallel to the camouflage effect that do not influence it equallly. For each factor considered, it can be said that it supports the camouflage effect mostly when it is similar to the state or properties of this factor in the surroundings. In first place, movement or action influences the possibility of detection the most. Therefore the statics or dynamics of a military object is crucial to its recognition. Secondly, pattern and colour influence target recognition, which is also included in the research. A silhouette, being the edge of a surface and volume that borders the surroundings, is also very important. When these two properties of a target object differ greatly from the silhouettes and volumes of bodies in the surroundings, the detection of the object is prolonged. Lastly, there is the sound and size of an object, where, besides the sense of sight, hearing is also activated. The factors mentioned above are a human discovery technique, but we can also find them in the animal world, which knew the phenomenon of camouflage much earlier than human beings [1, 23]. Looking at the factors that influence camouflage efficiency in terms of their order of importance, an obvious connection with the historical development of camouflage is easily demonstrated. Even from the beginnings of camouflage, it was realized that the most effective state to be in to hide an object is immobility. Pattern and colour were involved in the art of camouflage during WW1. They had a principal role in the 20th century until the implementation of scientific approaches that skillfully influenced the silhouette and surface of military objects through the degradation of shapes and the pixelised appearance of contours and a multilevel texture, which act on different levels of perception and detection [6 - 11]. The demand for the multilevel functions of camouflage patterns arises from the biophysics of the human visual system and takes an active part in the two visual systems: a focal for observing and detecting details and ambiental for a general view of the environment [24 - 27]. The function of the multilevel structure was further supported with the use of micro and macro patterns, both of which act at two observing distances at the very least: near and far (detection with the eye and optical devices). A hyperstealth pattern with micro and macro elements is presented in ***Figure 4***. The illusion of depth is achieved with bigger dark surface areas [28].

A special scientific approach to camouflage was discovered in 2003 in Japan (University of Tokyo). Japanese scientists created a camouflage system in which a video camera simultaneously ac-

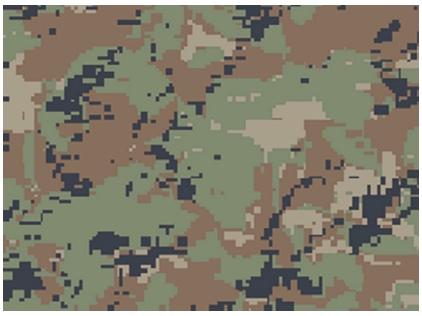

*Figure 3. Camouflage pattern generated by self-similar functions for areas of leaf woods [22].*

quires visual data from the background of a human body and displays them on cloth using an external projector (also liquid crystal displays). In practical terms, a view from behind an object is projected on the target object, resulting in its visual integration into the surroundings [29].

## Experimental part

The experimental work was divided into two parts: The first part was an analysis of the Slovenian urban environment, shape analysis and shape classification. The second part comprised the development and analysis of a procedure for camouflage pattern design. On account of the technical demands of a pattern given by the Ministry of defence, preliminary research was also conducted before the experimental part. This research involved the analysis of visual acuity as well as the recognition and perception of different types of raster and shapes at specified observing distances [12, 30].

### Analysis of the Slovenian urban environment

The capital of Slovenia, Ljubljana, was chosen as a representative Slovenian urban environment. Morphologically the city is composed of many areas of interest with different architectural characteristics, in which digital images were acquired, i.e. buildings of the old town, buildings of national interest, business buildings, modern architecture, residential premises, shopping centres, as well as the textures and reliefs of city buildings.

***a.) Image data acquisition***

Digital images were acquired from a frontal view using a Canon EOS350D with a Canon EF-S 18 - 55 mm 1:3.5 - 5.6 lens, and a Canon PowerShot S3 with a 6.0 - 72.0 mm 1:2.7 - 3.5 lens. The images were acquired at different distances from the objects (shapes) so that the different sizes of the objects could be analysed, including a macro view of the textures of the objects. All in all 500 digital photos were taken in different areas. Digital images were selected and divided into micro and macro elements required for pattern composition. Micro elements comprise wall reliefs, frontages, details of windows, doors, pavements, asphalt, railings etc. Macro elements are larger parts of the city: frontal views of squares, streets, roads, buildings, etc. Digital images were visually analysed and target shapes and sequences of shapes were detected, Many image examples were also transformed in size, which enabled a comparison of shapes, groups of shapes and repeats. Textures were extracted from images of buildings and classified in a separate group of shapes. The shadows of objects which would influence further image processing were excluded from the analysis of digital images. Images of representative city areas are shown in ***Figure 5***.

***b.) Image processing***

Digital photos were processed with software for processing bitmap images Adobe PhotoShop CS3 [31] and software for image analysis - ImageJ [32]. The procedure for image processing included:

- the pre-processing of digital images with software Adobe PhotoShop: the correction of tonal and colour gamut and contrasts,
- the selecting and clipping of target elements and the correction of perspective,
- the colour and compositional simplifications of 24 bit images in an RGB colour space for a greyscale reproduction and region-based representation of images in the three index colours selected,
- definition of the contours (edges) of element surfaces and line-based representation using ImageJ software [33].

***c.) Shape analysis and classification***

The definition, classification and sequencing of shapes included visual analysis. Through visual analysis, extracted urban shapes and repeats were selected and classified into groups according to morphological, geometrical, optical and camouflage properties and similarities and/or formal distinctions between shapes [34].

***d.) Composition of urban elements in a repeat***

The methods of composing the shapes and sequences of shapes in a pattern repeat were defined after the evaluation of the first phase of the experimental part. Here, the aesthetics and formal view of a pattern composition, which is derived from art theory [35, 36], was upgraded taking into consideration the camouflage effect and optical regulations of pattern composition. During the experimental work, three procedures for pattern composition were defined and evaluated. The first procedure was a basic combination of simplified urban shapes and sequences of shapes extracted from an urban environment. This procedure did not evidently interfere with the elementary organisation of the original urban elements. The other two procedures were carefully planned and involved major interference with the shape morphology, i.e. the form transformation and advanced digital processing of the shapes. Moreover, a multilayer structure was used, and the optical effects of pattern elements were carefully evaluated. In addition, the theoretical and practical fundamentals of pattern repeat, which were presented in the theoretical part, were systematically applied.

In dependence on the procedure and the planned optical results for the patterns,

*Figure 4. Hyperstealth pattern with micro and macro elements [28].*

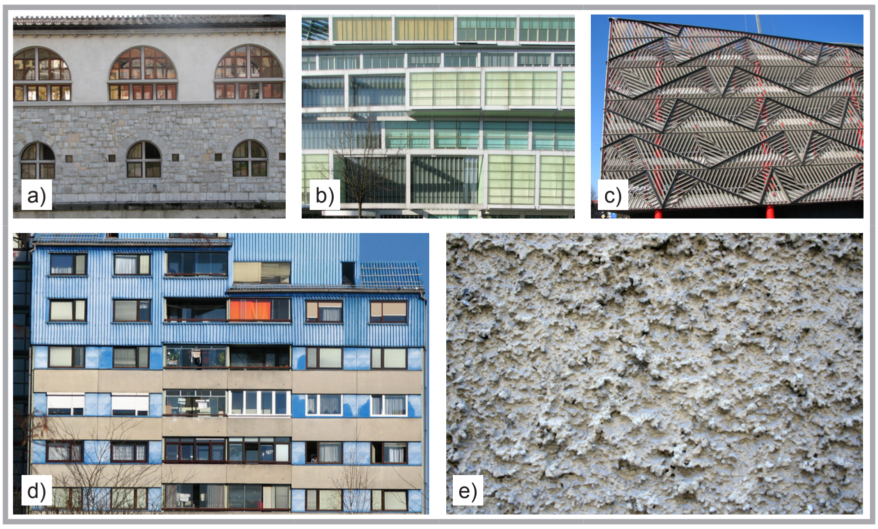


***Figure 5****. Representative target areas of the Slovenian urban environment; a) old town centre, b) business facilities buildings of national interest, c) modern architecture, d) residential areas e) textures and surfaces.*

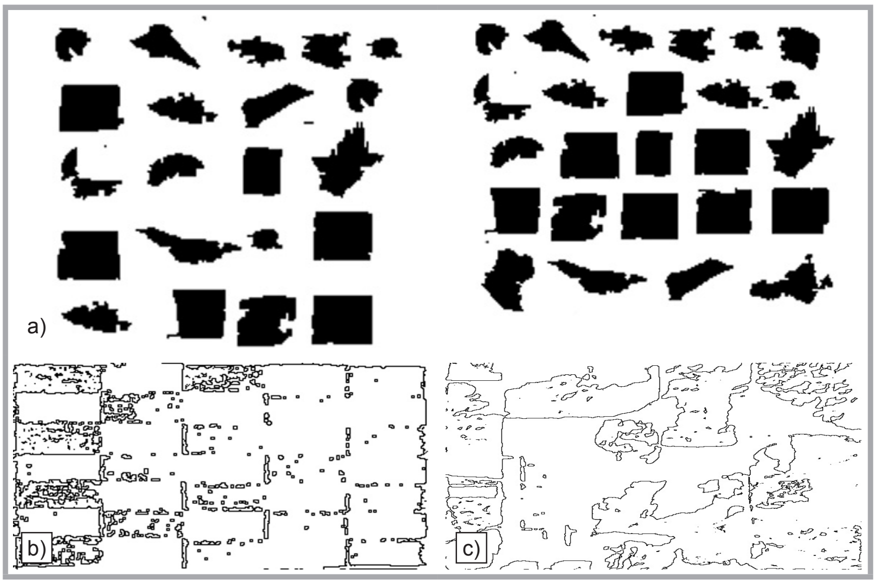


***Figure 6.*** *a) Law of similarity - elements with similar shape (round, square) are visually connected, b) law of closure - the disposition of micro elements that create close forms have advances prior to open groups of elements, and c) the visual self-similarity of shapes.*

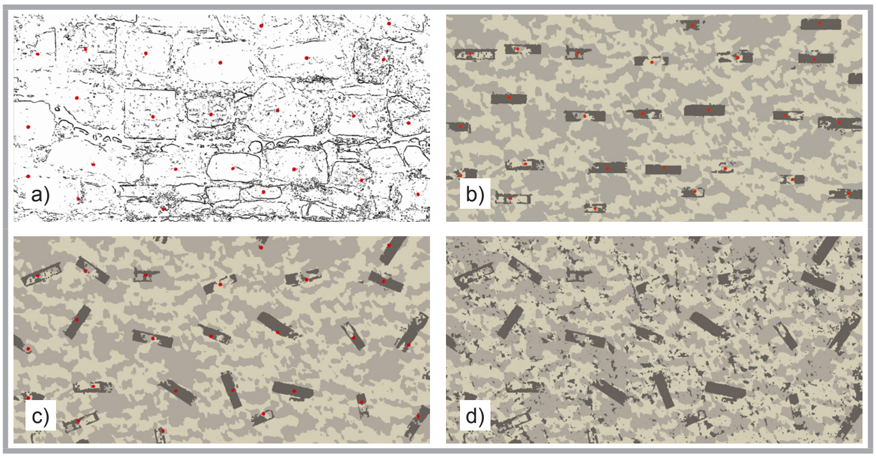


***Figure 7.*** *Visual effect of the application of defined centres of mass, the rotation of shapes and the addition of microelements in a repeat of a pattern; a) centres of mass, b) shape organisation and grouping, c) rotation and translation, d) addition of microelements.*

the following principles were considered and used in various combinations:

- the hierarchy of factors affecting the camouflage effect (pattern, colour, form),
- the principles of the Gestalt theory of perception,
- consideration of the fundamentals of fractal geometry (the self-similarity of shapes and groups of shapes),
- the pixelisation of shapes and contours (the digitally decomposed form of shapes and digital non-uniform edges of shapes),
- consideration of the positions of shapes in the camouflage pattern in relation to the positions of elements in a real urban environment (visual definition of centres of masses of selected shapes and their application on the surface of a camouflage pattern),
- the planned rotation and translation of shapes in a pattern,
- the optical mixing of colours in multicolour structures [37].

The visual effects of the use of two principles of Gestalt theory in an urban environment, i.e. The Law of Similarity and Law of Closure, as well as the presence of fractal geometry in the urban environment, which were used in camouflage patterns, are presented in ***Figure 6***.

The application of defined centres of mass in the line-based representation of a certain urban detail, the rotation of shapes, shape organisation, and in the grouping and addition of microelements in a repeat of a pattern are presented in ***Figure 7***.

***e.) Analysis of methods of designing a camouflage pattern***

The effectiveness of methods used was analysed visually in collaboration with the Slovenian Ministry of Defence and Armed Forces, which demand a pattern in three colours. This requirement was considered during the creation of the design. Camouflage patterns were printed on paper (Ink jet Canon Image pro 8400, CMYKLCLM, RIP Wasach) in three representative colours of the Slovenian urban environment with defined L*a*b* values, which resulted from the parallel research [38]. Three colours were used and their colour values were as follows: background in the brightest color: $L^* = 87$, $a^* = 0$, $b^* = 15$, medium bright colour: $L^* = 75$, $a^* = 1$, $b^* = 8$, and dark colour: $L^* = 42$, $a^* = -1$, $b^* = 2$ [12].

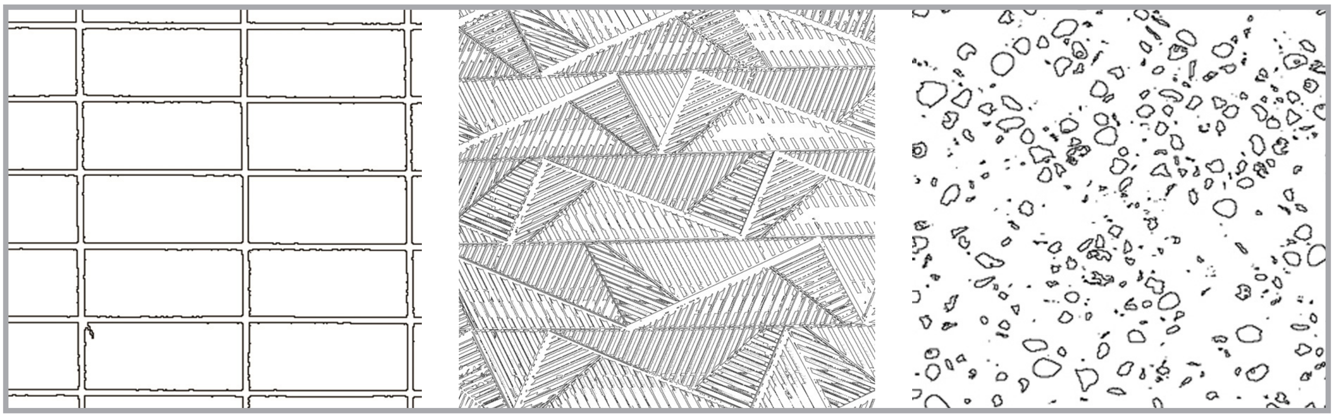

*Figure 8. Regular, semi regular and irregular repeats of the Slovenian urban environment.*

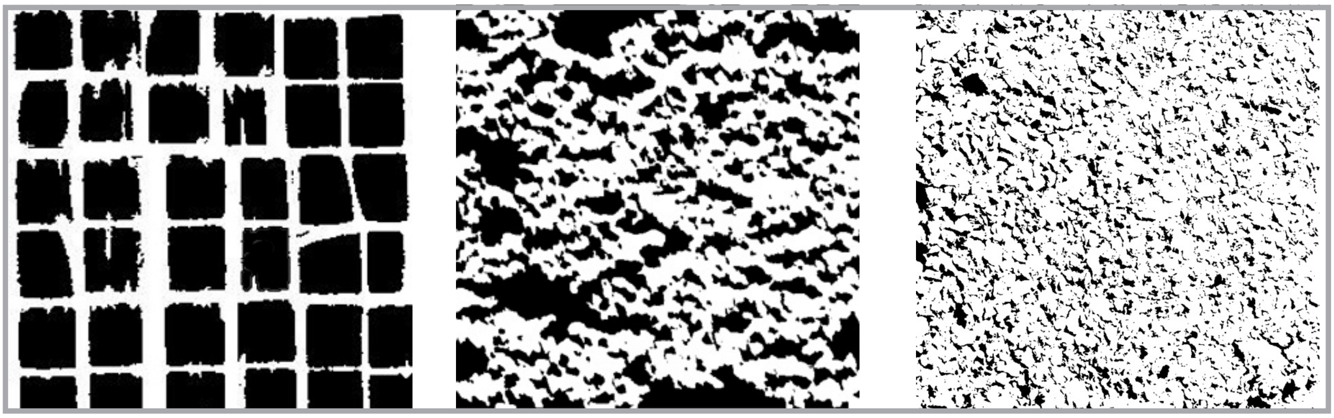

*Figure 9. Region-based shape representation of geometric shapes, organic shapes and microelements.*

## Results and discussion

### Analysis and classification of urban repeats

Visual analysis of the line-based repeat representation prepared using software for image analysis resulted in the definition of the three main groups of repeats in the Slovenian urban environment. The repeats of shapes extracted were grouped in regular repeats, semi regular repeats and irregular repeats, depending on the repeat step, the organisation of shapes and their sequences. Regular repeats had a very simple step of repeat - 1 or 1/2. In a vertical and horizontal direction the shapes were regularly positioned along the repeat, without declinations, translations or rotations. In semi irregular repeats the steps were 1/3, 1, and the shapes were positioned with some deviations in the vertical, horizontal and diagonal directions of the repeat. Irregular repeats were not visually describable with any regulation. In these repeats the shapes seemed to be randomly positioned on the surface, with many changes of direction. In ***Figure 8*** regular, semi regular and irregular repeats are presented.

As expected, the results showed that the prevailing urban repeats were organised horizontally and vertically and, consequently, were not adequate for direct application in the pattern. The detection of these repeats would occur at smaller distances, which is why these regular sequences of shapes had to be rearranged and deconstructed into an irregular composition before being used in the patterns.

### Analysis and classification of urban shapes

Visual analysis of boundary-based shape representation using software for image analysis resulted in a definition of three main groups of shapes in the Slovenian urban environment: geometric shapes, organic shapes and microelements (comprising textures of urban objects). The shapes, which in form resembled shapes, that could be defined with a geometrical equation (square, rectangle, triangle, circle) were included in the geometric group of shapes, which was most extensive because geometrical aesthetics is one of the most important distinctions of urban environment constructed by human beings. Organic shapes were less evident in the urban environment, as they had an amorphous and irregular form, which was not describable with any geometric shape. Apart from other functions, organic forms were also used to decompose the regularity of geometrical shapes. The third group of shapes were microelements, which included both geometric and organic shapes, with the difference that the first two groups had bigger dimensions of elements. Region-based shape representation of geometric shapes, organic shapes and microelements is presented in ***Figure 9***.

The predominantly square (geometric) urban shapes posed the same challenge as with regular urban repeats: how to combine them in a pattern not recognisable at smaller observation distances. This is why these shapes were additionally processed with the use of surface pixelization and contour degradation. This principle was enabled with the help of organic shapes and layers of microelements, which were applied to geometrical shapes (covering, summing, extracting, etc.).

The pixelisation and contour degradation of a dark urban element is presented in ***Figure 10***.

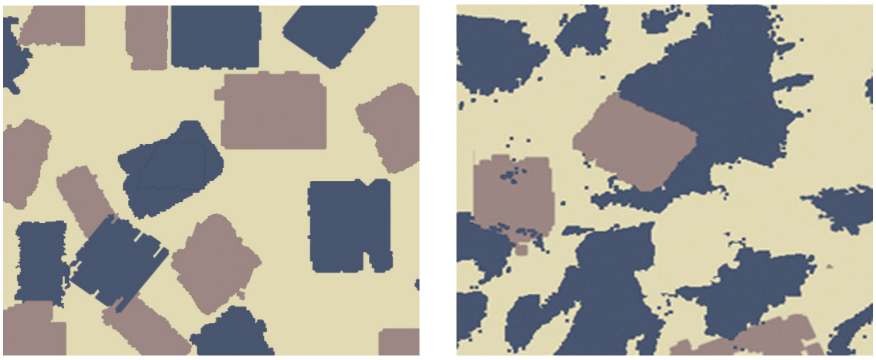

***Figure 10.*** *Pixelisation and contour degradation of a dark urban element.*

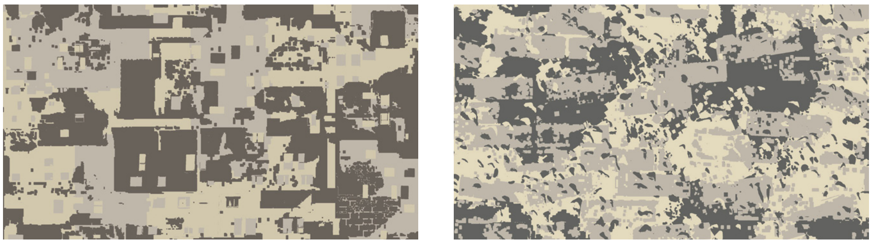

***Figure 11.*** *Patterns with a simple representation of urban shapes and repeats.*

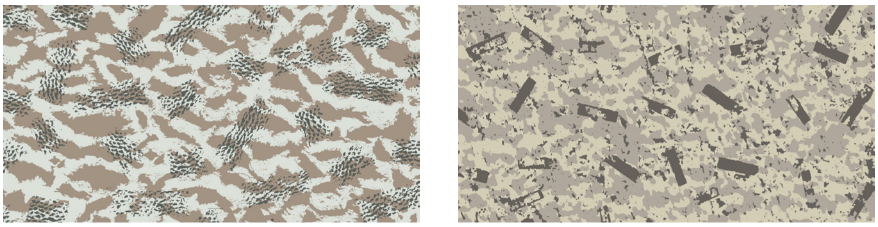

***Figure 12.*** *Patterns with a planned procedure of shape composition.*

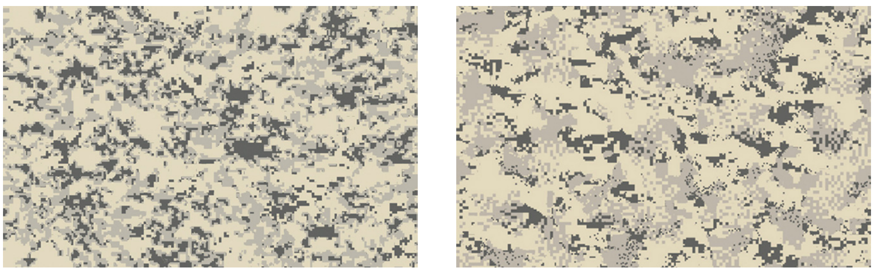

***Figure 13.*** *Third group of camouflage patterns (digital patterns).*

## Composition of patterns

The outlines of shapes extracted were morphologically completed using software for bitmap image processing, and systematically combined in a camouflage pattern, taking into account aesthetics, principles of pattern design, the optical effects of shapes, repeats, and requirements concerning pattern and shape detection. All the patterns were composed of a multilayer structure. In all cases the first layer was the background, while the other layers were composed of different sequences of extracted and processed shapes. The pattern composition experiments resulted in the definition of three procedures for camouflage pattern composition and evaluation of their applicability.

## The first procedure: a simple copying and representation of urban shapes and repeats

The first method was a simple overlaying of selected shapes and sequences of shapes extracted from digital images. The first step of this procedure was positioning larger elements in the background. The organisation of these elements was similar to that of elements (shapes) of real urban buildings. Layers containing smaller shapes were added in the next steps of the composition, with the intent of hiding easily detectable large geometrical shapes. Where needed, shapes were also formally changed; therefore their size was increased or reduced. Finally, more attention was given to the final aspect of the pattern and its visual effectiveness. Therefore some shapes were reorganised and post processed. In ***Figure 11*** two examples of a camouflage pattern are presented using the first method.

## The second procedure: a planned composition of shapes

The second method included a carefully planned design of the pattern. Shapes were positioned with respect to the centres of mass of shapes in urban elements and buildings. Where shape sequences were too regular, they were additionally transposed and relocated. Moreover, the shapes were changed with the help of rotation, translation and reflection, as presented in ***Figure*** *7*. In ***Figure 12*** two examples of a camouflage pattern made with the second procedure are presented.

## The third procedure: digital patterns

The third procedure was developed from the random positioning of smaller digital shapes according to a carefully planned design. The patterns of this group were designed in accordance with contemporary trends in the art of camouflage, which consider the digital appearance of a pattern. These trends are founded on the multilevel raster used in patterns, in digitalisation (pixelisation) and digitally degraded shapes and in irregular contours (shape edges), as presented in ***Figures 6,*** *7* and ***10***. The patterns were composed of already prepared layers of organic shapes from the first and second methods. Their organic appearance was upgraded and completed with the help of a lower resolution in order to achieve pixelate contours. The layers with typical urban shapes were used to preserve the urban properties of the camouflage. Additionally, new layers, mostly composed of finely degraded small elements (i.e. digital elements) were used to emphasise the multilevel function of the patterns and the effect of volume (perspective). The horizontal and vertical orientation of elements in the pattern was avoided with the displacement of layers in different directions and angles. In ***Figure 13*** two

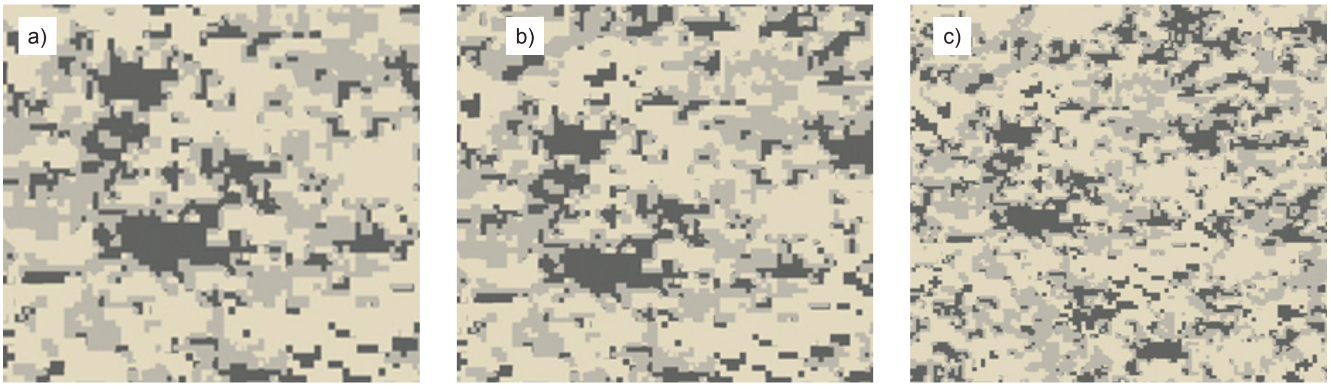


***Figure 14.** Influence of the gradation of a digital pattern on the optical effect and detection of shapes and repeats; a) 100%, b) gradation 80%, c) gradation 40%.*

examples of a camouflage pattern made with the third method are presented.

### Analysis of methods for camouflage pattern design

The first method was a simple representation of urban shapes and repeats in different layers without a planned composition, considering the camouflage function and optical properties of shapes and their organisation in the pattern. Disregarding the fact that the shapes and repeats of these patterns were more or less identical to the original urban shapes and repeats, the patterns were actually of no use because they were of little aesthetic value and rigid camouflage applicability. Despite additional retouching and correction in terms of camouflage principles, the problem with these patterns remained: easy detection of the sequences of shapes and their horizontal and vertical orientation.

The results of the second method were more predictable and aesthetically completed. The patterns appeared to be regular and somehow industrial with a pronounced structure in the two level raster. The problem arising from this method was the excessive similarity of these patterns to commercial patterns with small and easily recognisable repeats. The latter is a disadvantage for camouflage effect and was partly corrected with the addition of random elements and degradation of critical (visually outstanding) shapes. But results of this method were still unsatisfactory, and at this point the third method had shown its advantages. The shapes of patterns of the third group were highly decomposed and, taking into account the morphology of shapes, the division into geometrical and organic elements was not obvious. A pixelate appearance was achieved with the use of two layers in different colours in the background. With the use of the principle of pixelisation, digital patterns barely kept an urban appearance; therefore digitally processed urban shapes had to be additionally supplemented on the surface, as is shown in ***Figure 13***. The digital design and nonuniformity of shapes of this group of patterns was an advantage because of the possibility of pattern gradation after the design, enabling the adaptation of shapes to defined dimensions that resulted in proper camouflage effects at the observing distances requested. ***Figure 14*** presents the influence of the gradation of a digital pattern on the optical effect and detection of shapes and repeats.

## Conclusions

Military trends require camouflage patterns that visually and morphologically correspond to the specificities of the environments in which military action occurs and, in technical terms, meet the specifications of target detection and recognition. Military action is no longer focused on a typical environment, for example woods and desert, but has spread to different natural and man-made areas. The design of camouflage patterns that corresponds to all demands is possible only with selective acquisition of visual data in a certain environment and accurate analysis and classification of the digital representation of selected shapes and repeats. Digital data presenting different environments call for special approaches. For instance, the shapes and repeats of an urban environment are not directly applicable in a camouflage pattern, but need to be processed so as to adjust their morphology and improve their camouflage properties. Because of the prevailing horizontal and vertical organisation and regular (geometric) form, urban shapes and sequences have to be decomposed and combined with irregular (organic) shapes.

After a careful review of the principles for designing camouflage patterns already in use, none of the principles analysed was chosen as appropriate for the Slovenian urban environment. Because the pattern needs to be visually representative for different parts of the Slovenian urban environment (old town, industrial parts, modern architecture, etc.), new procedures were developed and examined. Among them only the procedure enabling the design of patterns with a digital (pixelate) appearance was chosen as appropriate, which was also confirmed by the Slovenian Ministry of Defence. The result of this procedure was the generation of digital patterns composed of plain graphical elements with a pixelate visual appearance and geometrically undefined shapes. In technical terms this procedure offers the possibility of processing patterns that disrupt a human figure, enables its visual assimilation into urban environments with different architectural properties and is flexible to changes in pattern dimensions influencing detection at various observing distances.

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