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Design and Evaluation of a Camouflage Pattern for the Slovenian Urban Environment

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Abstract. *The main purpose of using a camouflage pattern is to disrupt the basic shape of an object to hide or camouflage it in a specific environment. Department of Textiles at the Faculty of Natural Sciences and Engineering (University of Ljubljana, Slovenia) collaborated in the objective research project Knowledge for Safety and Peace 2006–2010 funded by the Slovenian Ministry of Defense. The basic goal of the research was to determine the procedure for designing a new camouflage pattern of the Slovenian urban environment and to visually analyze the chosen camouflage patterns in order to meet the visual properties, camouflage, and optical requirements. The experimental part included a selection of representative parts of the urban environment, classification of digital images, composition of a camouflage pattern, industrial pattern printing on textile, and finally, image and visual analysis of a digital pattern. The final camouflage pattern corresponded to all technical, formative, visual, and military requirements. © 2010 Society for Imaging Science and Technology.*
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INTRODUCTION

In nature, camouflage systems are important mechanisms for preserving the complex balance among spaces. Many of these systems have been developed due to their effectiveness on all levels of the food chain—for predators as well as for prey. The camouflage strategy, i.e., imperceptibility, for prey is to hide. By avoiding the confrontation with the predator, the prey reduces the possibility of encountering life-threatening situations, i.e., being attacked and killed (defensive or protective camouflage). On the other hand, the predator needs an offensive or attacking camouflage to be imperceptible during a successful hunt and attack.[1–3] Animals have evolved a range of modes which help them not to be perceived, e.g., protective colors, mimicry, countershading, disruptive coloration, defensive color patterns, and covering with the materials from their surroundings.[4,5] Since nature is a good example humankind can look up to, some of the principles mentioned above have been effectively used in the history for various purposes.

Nowadays, camouflage patterns are one of the most important components of the modern military strategy. They are also a part of the national identity, since almost every country has its own camouflage pattern. According to literature sources and historical facts on camouflage patterns, early army and military formations did not use camouflage patterns at all; their use as a part of military equipment began in contemporary history as a consequence of the development of military strategies. At the beginning of the 20th century, soldiers wore uniforms of very saturated and perceivable colors and only before the First World War, did uniforms began to imitate colors of nature (e.g., dark green and khaki). However, the first camouflage uniforms were single-colored and did not suit the requirements of disrupting human body shape.

The development of a camouflage pattern was enabled by the (experimental) work of naturalists and artists who transmitted some elementary principles of natural camouflage into human benefits.[1,2,5] The basic principle of traditional camouflage was the application of typical shapes and their groups, respectively, of the environment to a new media, i.e., military uniform. Moreover, during the application processes, shapes were also transformed and adapted in accordance with the technical and aesthetic specifications of the new media. A revolutionary breakthrough in the science of camouflage was made in the 1970s when O'Neill developed a new form of camouflage patterns. The latter were based on a two-level function (i.e., dual texture) and digital appearance of camouflage patterns.[6] O'Neill's ideas gained the most recognition through collaboration with the U.S. Army and U.S. Marine Corps.[7–9]

Not only the USA but also Canada made an important contribution to digital patterns with the Canadian Camouflage Pattern CADPAT, which was designed at the end of the 20th century.[10] The new approach to the camouflage pattern design was first used only in Canada and America; however, in the course of the last ten years, it has raised interest in some other countries as well. Digital patterns are designed mostly with mathematical algorithms, which simulate the appearance of digital images taken from a specific environment. Digital simulations of an environment are then processed, taking into account the requirements for visual and

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optical properties of a pattern, and its technical requirements. As a result, a pattern with digital visual properties is generated. The procedure is advanced and reflects a scientific approach to the camouflage problem; nevertheless, the challenge remains of how to camouflage an object in different backgrounds or how to design adequate patterns from digital images taken in different parts of a specific environment.

The starting point of the research was that every country which is a member of powerful military unions (e.g., NATO) needs to represent itself with a representative, national military uniform. The research was also based upon the fact that there are two opposite trends in the camouflage pattern design. On the one hand, regions involved in one country's military actions can be very different (e.g., forests, snowy regions, urban environment); therefore, one country should have different uniforms for each environment. However, on the other hand, the necessity for a single camouflage pattern, which is representative of one country, but can be used in different color schemes for different country environments remains.[11]

The Department of Textiles at the Faculty of Natural Sciences and Engineering (University of Ljubljana, Slovenia) collaborated in the objective research project *Knowledge for Safety and Peace 2006–2010* funded by the Slovenian Ministry of Defense, the basic goal of which was to develop a new urban camouflage uniform for the Slovenian Army. If all the requirements by the Ministry of Defense on camouflage patterns are to be summed up in only three requirements, they would be as follows:

(a) digital visual appearance,
(b) detection at certain distances of observation, and
(c) infrared (IR) protective properties.

The research was extensive and involved experimental work from different camouflage aspects, i.e., color, protective properties of the uniform, chemical and mechanical aspects, etc. The responsible researchers of experimental groups were Simončič, Bračko, Forte Tavčer, and Gabrijelčič.[12–14] This article presents only the part of the project in which the camouflage pattern was designed and its shapes and repeats were developed, taking into account the requirement for digital appearance and detection at certain distances.

THEORETICAL BACKGROUND

Detection of an Object

The main task of a camouflage pattern is to hide or camouflage an object from being detected by an observer. A pattern design should disrupt the shape of the object (e.g., human body, vehicle, and building) and make it visually as similar as possible to the environment in which it is located or is moving through. Detection of two- or three-dimensional (3D) objects depends on the properties of the object, the observer, and on the observing conditions. The object properties are shape, color, dimensions, size, etc. The observing conditions depend on natural light, expressed as daylight vision or night vision, depending on which photoreceptors are active in the retina (cone for daylight vision, rod for night vision), observation distance, interaction space object, etc.[15] The properties of the observer, who collaborates during object detection, can be indicated as psychophysical, i.e., in physical, physiological, and psychical terms the sensitivity and response of the whole human visual system (i.e., eye-brain) to light. The complex mechanism of object detection and camouflage is a simultaneous activity of many psychophysical properties of the human visual system,[15,16] i.e., visual acuity, temporal resolution, light and darkness adaptation, contrast sensitivity, and color, space, and depth perception.

However, it can be said that among all the parameters listed above, the most important observing condition is the distance between the object and the observer, which is required due to the process of recognition during pattern detection, while one of the most important psychophysical properties of the human visual system is visual acuity. The latter can be explained as the minimum distance between two borders that can be visually resolved. Visual acuity depends on the distance between the photoreceptors in the retina and is expressed in minutes of arc. Visual acuity α of an average observer is $1'$ and can be calculated with

$$\alpha = Y/L, \tag{1}$$

where Y is the size of an object and L is the distance between the object and the observer.

The visual acuity parameter needs to be involved and considered during the development of a camouflage pattern since it collaborates with other visual abilities of the human visual system for detection, resolution, recognition, and localization of shapes or groups of shapes in the camouflage pattern, and object detection in the background environment.[11,15,16]

Urban Environment

Trends in the art of camouflage dictate a specific camouflage pattern for each country, which enables its identification and in addition, different camouflage patterns for different environments throughout the country, i.e., natural (e.g., forest, desert, snowy landscape, and countryside) or urban (e.g., city and industrial environment). Armed forces in several countries solve the color and morphological characteristics of different environments with the same pattern but different color schemes.[11,17] Nevertheless, the best solution is to develop different pattern designs next to different color combinations for a specific environment. The necessity for a specific pattern for an urban environment arises from the battlefields now usually being cities and their urban surroundings.

Morphologically, the urban environment differs from the natural one mostly due to the origin of shapes since natural shapes more or less follow the functionality of natural objects (anatomy, physiology, etc.), while the shapes of urban objects are designed with regard to their use within the civilization of a certain development stage and urban requirements.[18–20] The morphology of shapes in the urban environment is apparently not as complicated as the morphology of organic shapes in the natural environment, which could bring to an overhasty conclusion that urban patterns are easier to design. However, it also needs to be taken into consideration that simpler pattern morphology (i.e., geometric shapes and orientation) can be more easily detected. Furthermore, it can be detected at longer distances. Consequently, urban patterns should also include other camouflage tricks which would successfully hide an object in an urban environment.

Use of Science and Design in Camouflage

The main purpose of using a camouflage pattern is to disrupt the basic shape of an object (e.g., people, buildings, and vehicle) to be able to hide or camouflage it in a specific environment. Disruptive patterns imitate the visual appearance of an environment and consequently, camouflage the object to prevent its detection regardless of its state (i.e., static or dynamic). The original meaning of the word *camouflage* was different than in modern terminology, and it was no earlier than in the 19th century that the meaning of the word was connected to fighting strategies and the army.[1,2]

In the past, the majority of camouflage patterns were designed by artists, who designed abstract shapes, applied them to patterns, and chose colors which were representative of a certain environment (e.g., walls, rocks, trees, wood, snow, city, and desert). Further development in camouflage led to the application of new scientific findings, resulting above all in digital camouflage patterns designed for a specific background (i.e., digital image of an environment). Shapes and repeats of these patterns are mostly processed with mathematical algorithms and they demonstrate real progress in the history of camouflage.[6–11] The principle of designing digital camouflage patterns includes acquisition of digital images of representative parts of a specific environment, preprocessing of digital images, and their processing onto a pattern, so that the visual appearance of a pattern imitates completely the scenery in which the object is located. Furthermore, advanced design principles also take into consideration the findings from various scientific fields, e.g., optics, visual perception, photometry, colorimetry, etc., and include them into pattern designs. Such an example is a dual-texture application in a camouflage pattern, which arises from two visual mechanisms of the human visual system, i.e., focal and ambient.[21–25] Therefore, the macro and micro pattern in such camouflage patterns are generated by taking into account two detection distances and two groups of shapes presenting both the environment and target object.

EXPERIMENTAL PART

The purpose of the present research was to determine the procedure for designing a new camouflage pattern of the Slovenian urban environment and to design a collection of camouflage patterns that meet all the technical, formative, visual, and most of all, military requirements. In this article, only the final camouflage pattern, which was developed in cooperation with the Slovenian Army and Ministry of Defense, is presented. The design method encompasses several principles, which were defined on the basis of the requirement that the pattern be suitable for various parts of the urban environment (e.g., old city, modern town, industrial parts, protocol buildings, etc.); therefore, the use of an algorithmically transformed digital image of certain scenery was not useful.

The experimental part included the following procedures and methods:

(a) selection of representative parts of the urban environment,
(b) preprocessing of digital images,
(c) transformation of digital images,
(d) classification of digital images,
(e) composition of a camouflage pattern,
(f) image analysis of a digital pattern,
(g) visual analysis of a pattern printed on paper,
(h) industrial printing of a pattern, and
(i) visual analysis of a pattern (i.e., detection).

(a) The chosen urban environment (i.e., Ljubljana, the capital of Slovenia) was divided into different representative parts, taking into account the urban properties and visual appearance of selected parts: buildings of the old part of the city, buildings of national interest (e.g., government buildings, parliament, ministries), commercial buildings, modern architecture, residential premises, shopping centers, industrial zones, textures, and relief of city objects.

(b) The preprocessing of digital images included three main tasks, acquisition, detection, and operations. The digital images were acquired in frontal view for the shapes not to get distorted due to the perspective. The images were acquired from different distances from the objects in order to analyze different object sizes, including the macroscopic view of object textures. The technical properties of the chosen digital cameras were as follows: Canon EOS350D with Canon EF-S 18–55 mm 1:3.5–5.6 lens and Canon PowerShot S3 with 6.0–72.0 mm 1:2.7–3.5 lens. The digital images were visually analyzed, and shapes and their groups were detected and normalized, which enabled a comparison of shapes, groups of shapes, and repeats (Figure 1).

(c) The transformation of digital images involved both region-based and boundary-based shape representation. The region-based shape representation was conducted with the index color function in the perceptual mode with ADOBE PHOTOSHOP CS2 software for processing bitmap digital images.[26] The boundary-based shape representation was conducted with IMAGEJ, a program for image analysis.[27] The region- and boundary-based shape representations are presented in Figure 2. Further steps were conducted mainly with one-dimensional signals (i.e., boundary-based shape representation). The representative shapes and repeats were also extracted from images in this mode.[28] Figure 3 presents an example of boundary-based angular and semiround shape of the urban environment and their geometrical simplification.

(d) The classification of shapes, i.e., shape similarity and matching, and classification into different groups was conducted visually considering the size of objects (i.e., macro or

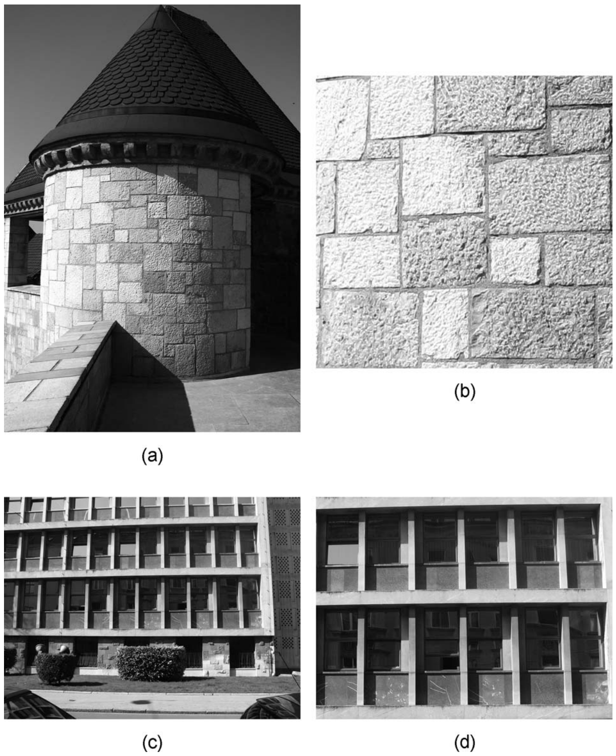


Figure 1. Shape detection and operations of digital images of urban environment.

micro) and their geometrical properties (i.e., organic or geometric).

(e) The composition of the camouflage pattern was focused on multilayer composition and took into consideration detection requirements; therefore, the observation distance which would enable shapes and repeats in a pattern to be indistinguishable was from 50 to 70 m, a technical requirement given by the Slovenian Army and Ministry of Defense. The composition of shapes and repeats included also some principles and theoretical facts of the Gestalt theory of perception of patterns or multitude of shapes, visual response of the human visual system (i.e., adaptation), two-visual systems, theory of optics, fractal geometry, and modern principles in the composition of a camouflage pattern.

The pattern was designed by composing selected shapes and their repeats. The latter were transformed in size and dimension, rotated around their centers of mass by multiples of the angle 11.25°, disrupted, located, and relocated on the pattern surface in different layers by using the position of shapes in the urban environment. The shapes were also given digital contours. The design included limitations and technical properties of industrial production (repeat dimensions 120×64.15 cm). In Figure 4, pattern layers are presented and their function is explained. The pattern is composed of seven layers, each including typical elements in a selected color. The final pattern is presented in Figure 5.

(f) The digital image of a multi-layer camouflage pattern was analyzed with software for image analysis.[27] The analysis included defining of surface areas of selected elements, percentage of total surface (rapport 120×64.15 cm)

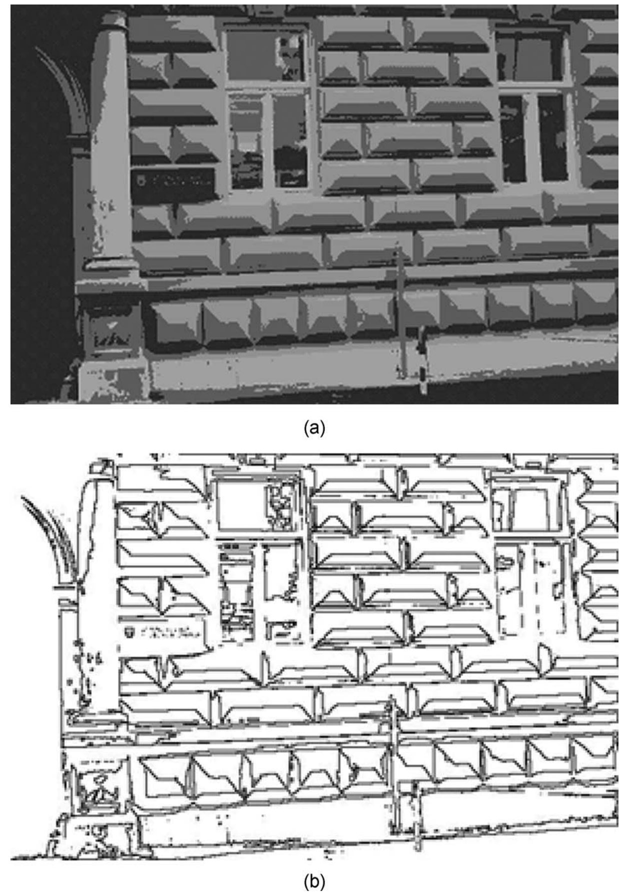


Figure 2. Region- and boundary-based shape representations of details of urban environment.

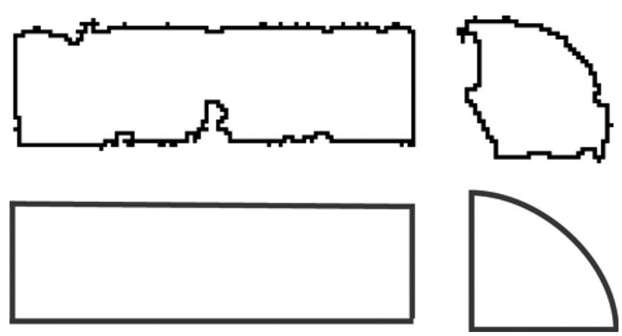


Figure 3. Boundary-based angular and semi-round shape of urban environment and their geometrical simplification.

covered with a certain color and type of elements, and defining centers of mass of shapes and their disposition. The area of different shapes and its analysis was important to control the shape size and consequently, shape detection from different (predefined) distances. Centers of mass were defined and analyzed in order to control shape disposition (orientation of groups of shapes in the pattern). Taking into account the theoretical facts of visual acuity[15,16] and the requirement that shapes of the camouflage pattern and its repeats not be detected from the observation distances 50 to 70 m, we calculated the average main dimension of shapes and the distance between the shapes from 1.45 to 2.05 cm

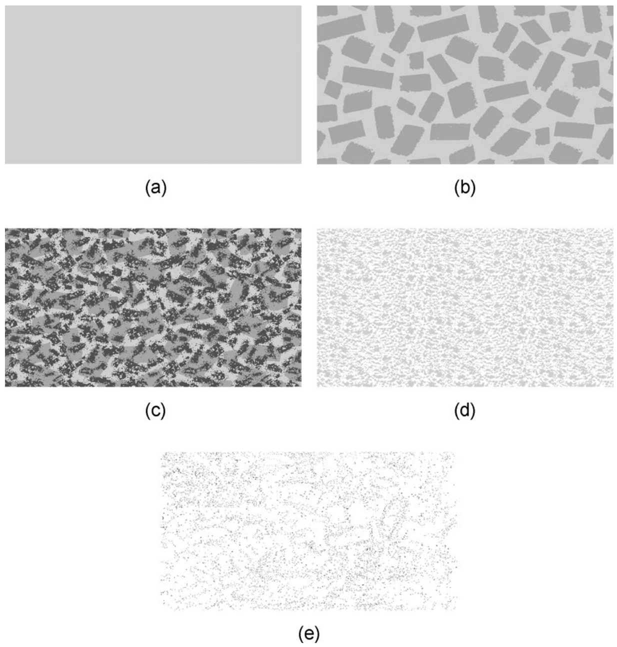


Figure 4. Pattern layers and their function. (a) Foundation in the brightest color. (b) Large urban shapes in medium-bright color, presenting shapes of average size from different urban parts. (c) Composition of urban shapes in dark color with disruptive shapes and contours. (d) Composition of a digitalized organic pattern, which presents organic shapes from the urban environment, was of the brightest color. This layer was in the background color and provided other shapes with distorted appearance. (e) United layers numbers 5, 6, and 7 with microelements in all three colors—the position of microelements is on the contour of shapes of the 2nd layer. Their function was to make contours less detectable.

[cf. Eq. (1)]. Evidently, the surface of shapes was not to be full since this would make them more detectable. The size 2.05 cm was therefore used with variations in shape direction. The results of intermediary steps of experimental work were visually analyzed on paper prints in natural size.

(g) and (h) The camouflage pattern was printed with rotary screen printing on woven fabrics, chosen by the Slovenian Ministry of Defense. The construction parameters of the fabrics were 100% cotton, plain weave, warp density 40/cm, weft density 20/cm, mass per square unit 229 $\mathrm{g/m^2}$, breaking force in warp direction 86 daN and in weft direction 78 daN, breaking elongation in warp direction 25% and in weft direction 15%, and fineness of warp and weft 8 tex. The requirement by the Slovenian Army and Ministry of Defense was to produce a three-color camouflage pattern with a camouflage effect within the visual and IR range, i.e., background color (color of woven fabrics $L^*=75.65$, $a^*=0.82$, $b^*=5.82$) with medium-dark ($L^*=53.47$, $a^*=1.25$, $b^*=6.27$) and dark colors ($L^*=33.9$, $a^*=-0.41$, $b^*=2.62$). The color values were measured with Datacolor Spectroflash SF600X spectrophotometer (Datacolor International, USA) with the following specifications: $d/0$, specular component included, standard observer 10°, illuminant D65, four layers. The spectral and color properties of camouflage pattern shapes were selected on the basis of parallel experimental work which was also included in the project.[29–31]

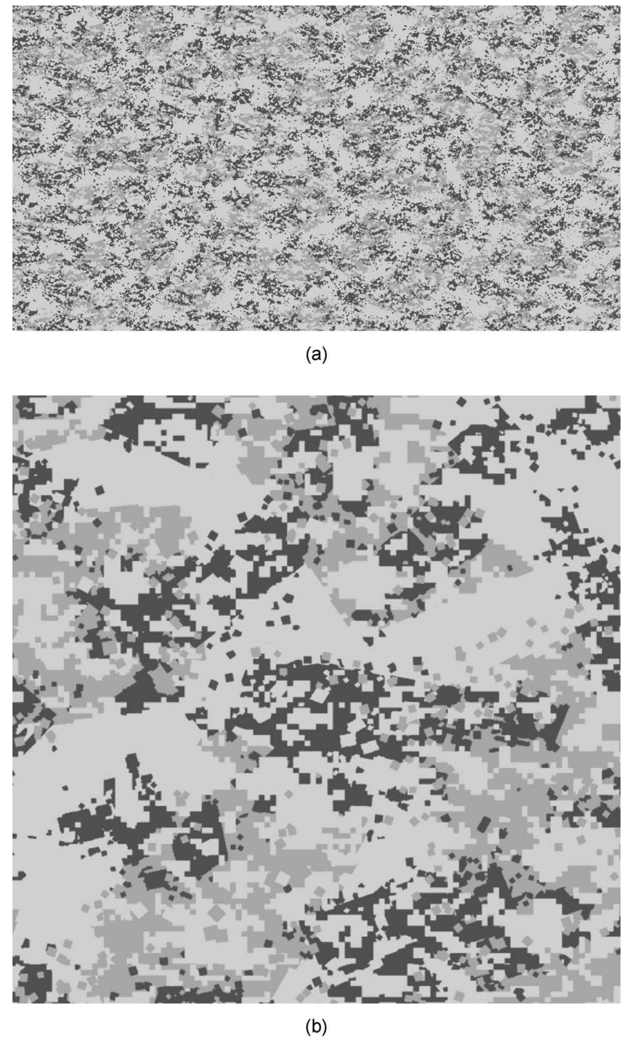


Figure 5. The final camouflage pattern for Slovenian urban environment and its detail.

(i) The visual analysis of the pattern and detection under the predefined observing conditions was undertaken on a 3D object, a person dressed in a military uniform, which was constructed under the technical specifications of the Ministry of Defense. There were 25 observers, from the age of 24 to 35. The analysis took place in the urban environment in August. The average observing conditions were 9611 lux (standard deviation of 3287 lux) and 6286 K (standard deviation 1284 K). The observing method was to start detection 250 m away from the person dressed in the camouflage uniform and then to approach them for observation at predefined distances (distance difference of 5 m and observing time of 5 s). With the method given, the observers were asked to define six limit distances, each causing a certain visual effect as is explained in the discussion on visual analysis in the section *Visual Assessment of Camouflage Pattern*.

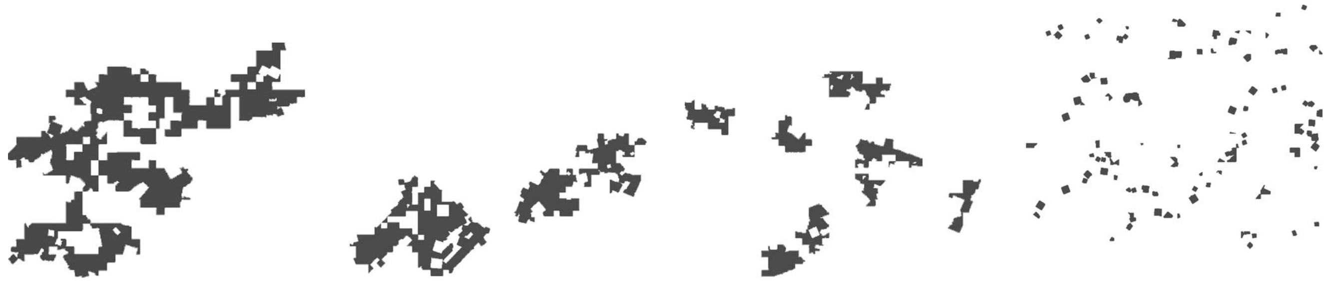
RESULTS AND DISCUSSION

Image and Shape Analysis of Slovenian Urban Environment: Analysis of Shape Morphology

The image and visual analysis of the boundary-based representation of parts from the Slovenian urban environment

Table I. Mean values of size and surface of large, medium, small, and micro shapes.

Large	Medium	Small	Micro
Size: above 2.5 cm Surface: above 6.25 cm^2	Size: 1–2.5 cm Surface: $1-6.25$ cm^2	Size: 0.5–1 cm Surface: $0.25-1$ cm^2	Size: below 0.5 cm Surface: below 0.25 cm^2



was first focused on the analysis of shape properties, e.g., angular, round, organic, geometric, nongeometric (to imitate the morphology of the environment), and second, on the analysis of shape area (to satisfy the optical response of the human visual system by detecting the object). The results of the image and visual analysis of the extracted shapes indicated that the shapes can be classified into three main groups: group of geometric shapes, group of organic shapes, and group of microelements. The group of geometric shapes, i.e., geometrically defined shapes, mainly included angular elements; nevertheless, round shapes occurred as well. Organic shapes were geometrically nondefined plain structures, which were not very frequent in boundary-based shape and repeat representation of digital images; even so, they were still well represented in a heterogeneous urban environment. Their contours and dimensions were irregular. Geometric and rectangular shapes were in fact most commonly represented in the urban environment; however, it needs to be taken into consideration that these shapes are unsuitable for direct application in a camouflage pattern, which is due to their regular and, consequently, easily detectable and recognizable contours. Therefore, before integrating these shapes into the pattern, they were additionally processed, especially their contours, and their incorporation into the pattern was thoughtfully planned. On the contrary, nongeometric shapes need less postprocessing due to their irregular contours and dimensions and are consequently more difficult to detect and recognize. In combination with geometric shapes, nongeometric shapes reduced regularity, the latter not being effective in camouflage. Special composition effects were attributed to microelements, the size of which was in general minimal in comparison to the other two groups of shapes. The group of microelements was used to disrupt geometric and organic shapes and consequently make them less recognizable.

Urban Camouflage Pattern

In Fig. 5, the camouflage pattern chosen by the Slovenian Army and Ministry of Defense is presented.

Shape Analysis with Regard to Color and Size

The use of image and shape analysis resulted in defining the number of groups of elements regarding their size and surface. The requirement of the Slovenian Army being that the distance of pattern detection be between 50 and 70 m, the mean shape sizes were calculated and resulted in 1.45 cm for the 50 m distance and 2.05 cm for the 70 m distance [cf. Eq. (1)]. The limit size values for elements from 1.45 to 2.05 cm consequently expanded by 0.45 cm, i.e., from 1 to 2.5 cm, to include tolerance during observation at distances, defined in the preliminary research.[11] The image analysis of the urban environment had indicated that the three main groups of elements, differing in size and surface, can be defined in the Slovenian urban environment. The group of elements smaller than 1 cm^2 included a large number of elements and was consequently divided with image analysis into two subgroups, small and micro. Examples of large, medium, small, and micro elements is graphically demonstrated in Table I. The theoretical equation for visual acuity is one dimensional, while the shapes in the camouflage pattern are two dimensional. The mean size values and mean surface values of the four groups of shapes are presented in Table I.

The target group of shapes which were most important with respect to detection from 50 to 70 m is the group of medium-size shapes with the surface from 1 to 6.25 cm^2. The elements with smaller and larger surface were added to enable a multilevel function of the pattern, disruption of shapes, and blurring of shape contours. However, as it can be seen from the pattern (Fig. 5) that the surface of large shapes is anything but uniform due to digital elements and microelements. Consequently, much shorter distances are needed to detect these shapes. The size and surface area of shapes did not depend on the color of shapes; therefore, the bright, medium-bright, and dark color shapes of the pattern were present in all four groups, micro, small, medium, and large shape sizes.

The next step in the image analysis was the calculation of number of elements, their mean area, and total fraction area of shapes (in cm^2 and percentage) in different colors and sizes, which are presented in Table II. In Table III, the mean values of surface area of elements and total fractional area in the pattern repeat are presented with regard to the size and color of shapes.

Table III indicates that bright colored elements (shapes)

Table II. Number of elements, mean area, and total fraction area of shapes in different colors and sizes.

Group, area (cm^2)	Micro (below 0.25)	Small (0.25–1)	Medium (1–6.25)	Large (above 6.25)
		Bright-color shapes		
No. of particles	1804	226	100	60
Mean area (cm^2)	0.055	0.500	2.021	64.059
Standard deviation (cm^2)	0.060	0.205	1.133	65.420
Fraction area (cm^2)	99.864	113.859	202.076	3892.082
Fraction area (%)	1.3	1.5	2.6	50.6
		Medium-color shapes		
No. of particles	5894	311	155	57
Mean area (cm^2)	0.05	0.45	2.672	14.487
Standard deviation (cm^2)	0.050	0.182	1.427	7.714
Fraction area (cm^2)	317.26	139.84	414.196	825.744
Fraction area (%)	4.1	1.8	5.4	10.7
		Dark-color shapes		
No. of particles	6498	416	350	36
Mean area (cm^2)	0.052	0.493	2.364	8.952
Standard deviation (cm^2)	0.044	0.201	1.199	2.234
Fraction area (cm^2)	338.021	205.043	827.548	322.285
Fraction area (%)	4.4	2.7	10.7	4.2

have on average the largest mean surface area (64.059 cm^2) and, consequently, total areal fraction of 56%. Bright colored elements are followed by medium-bright (mean area of 14.487 cm^2) and dark elements (mean area of 8.952 cm^2), the total areal fraction of which is in both cases 22%. Such a composition is important due to the camouflage effect, detection of a camouflage object, and technical limitations at printing. Detection of dark-color shapes occurs at shorter distances than detection of medium-bright color shapes. Regardless of the same total fraction area of dark and medium-bright color shapes, dark-color shapes enable a camouflage effect at longer distances (ΔE between the darkest and brightest color is 41.89), while medium-color shapes enable a camouflage effect at shorter distances from the object (ΔE between the medium-bright and brightest color is 22.19). The application of the brightest color as background and darker colors as shapes was required by the Slovenian Army; furthermore, the practicability of this color-shape order was also proven in the preliminary research,[11] where a simple two-color pattern with darker shapes on a brighter background was generally detected at significantly shorter distances than the same pattern with brighter shapes on a darker background.

The total mean surface area of elements is 8.01 cm^2, 2.83 cm expressed in one dimension. The pattern, its shapes, and colors should therefore theoretically mix on one single-color surface at the approximate observation distance 97 m. Due to large shapes, which are on average twice as large as the mean area (but better represent the actual urban size of shapes), the pattern in practice visually produces a single-color surface with optical mixing at longer distances. The large elements cover altogether two thirds of the surface of repeats (65.5%), followed by the total-fraction area of medium-size elements (18.7%), microelements (9.8%), and small elements (6%). The total fractional areas and mean surface areas of elements are of great importance to pattern composition, its aesthetics, and visual appearance. Nevertheless, in practice these parameters do not influence the exact observation distance at which a pattern is or is not recognizable or at which a pattern cannot be detected. The exact visual and optical properties of the camouflage pattern were in fact planned and achieved with digital surface disruption of large and medium-size shapes and their contours. In the camouflage pattern design, these effects were achieved with the addition of micro and small shapes, which covered the large- and medium-size shapes and especially their contours.

Analysis of Centers of Mass

On account of the nonuniform surface and geometrically undefined contours, the disposition and orientation of shapes were difficult to define in the final camouflage pattern by visual observation (cf. Fig. 5). The shape disposition

Table III. Mean values of surface area of elements in different colors and shapes.

Mean surface area (cm^2)					
Elements	Micro	Small	Medium	Large	Mean value
Bright	0.055	0.500	2.021	64.059	16.659
Standard deviation					31.611
Medium-bright	0.050	0.45	2.672	14.487	4.415
Standard deviation					6.815
Dark	0.052	0.493	2.364	8.952	2.965
Standard deviation					4.115
Mean	0.052	0.481	2.352	29.166	8.01
Standard deviation	0.003	0.027	0.326	30.345	14.137
Total fraction area (%)					
Elements	Micro	Small	Medium	Large	Total
Bright	1.3	1.5	2.6	50.6	56
Medium-bright	4.1	1.8	5.4	10.7	22
Dark	4.4	2.7	10.7	4.2	22
Total	9.8	6	18.7	65.5	100

over the entire repeat was analyzed by measuring the geometrical centers of mass, and the x and y coordinates of surface elements. The disposition of shapes and their groups directly influenced the detection of the camouflage pattern and, in consequence, of the person in the camouflage uniform. Every regular sequence of shapes can result in faster detection since the human visual system groups separate shapes into more easily detectable structures according to the Gestalt theory of patterns. In the camouflage pattern, only the centers of mass of large- and medium-size shapes were analyzed, for these two groups were, due to their size, more easily detectable and influenced the appearance possibility of the unwanted visual groups of shapes the most.

In Figures 6 and 7, the x and y coordinates of centers of mass of large- and medium-size shapes are graphically presented on the pattern surface. Colors 1, 2, and 3 correspond to the background color 1, medium-dark color 2, and dark color 3.

Centers of mass of large- and medium-size elements in all three colors help determine orientation and direction of elements in different parts of the pattern. Figures 6 and 7 indicate that there is no leading direction of elements but only groups of a few elements organized in the defined direction due to the fact that regardless of the orientation of shapes in the urban environment (mostly horizontally and vertically), which can be easily detected, this orientation of elements was not used in the pattern. However, with random movements of different shapes in the pattern, very irregular steps of repeats were achieved. Large- and medium-size shapes were irregular and disruptive; consequently, centers of mass of elements were not necessarily within the surface of these elements. The orientation of large- and medium-size elements in the pattern played an important role at different observation distances, the situation being the same as in the urban environment, where orientation of urban elements of different sizes can be noticed at different distances.

Visual Assessment of Urban Pattern

The visual assessment of the camouflage pattern on a 3D object (i.e., human body) is presented in Figure 8. The observers were asked to evaluate the camouflage pattern regarding:

(1) Complete optical mixing of shapes and color on a single-color surface,
(2) recognition of a larger non-uniform surface and undefined shapes,
(3) recognition of a defined pattern and different shapes on the object,
(4) recognition of different colors and shapes of single elements in the pattern,
(5) recognition of shape properties and their contours, and
(6) recognition of finest details in the pattern (i.e., microelements).

The visual assessment of the camouflage pattern on the 3D object resulted as expected in detection and recognition of the pattern at different distances by different observers. From Fig. 8, a short visual evaluation of the camouflage pattern and its visual effects can be drawn, namely:

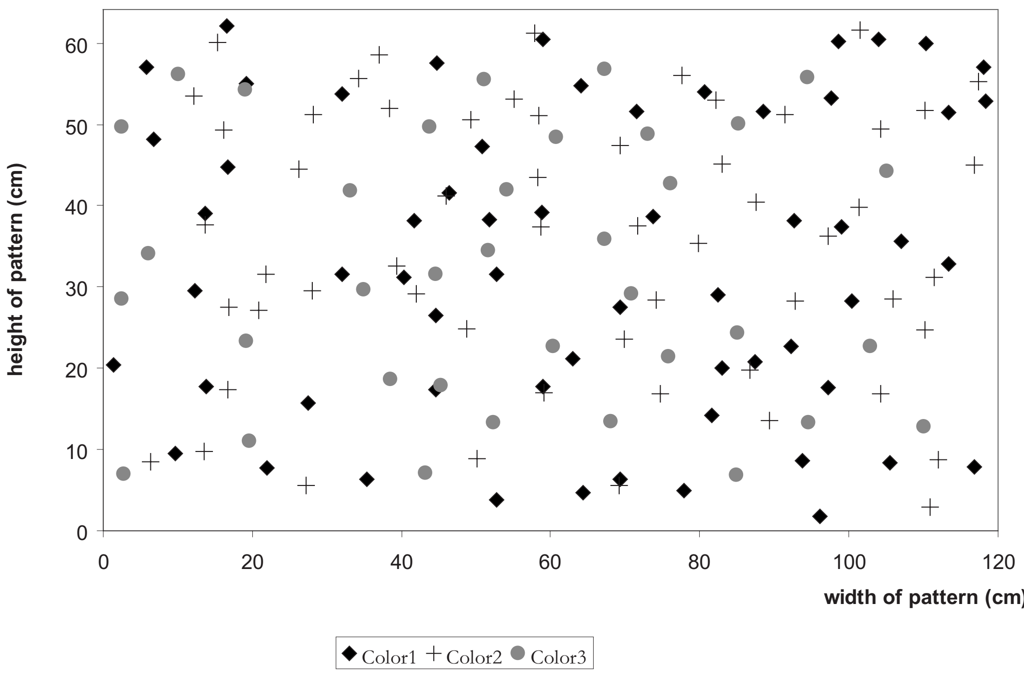


Figure 6. *x* and *y* coordinates of centers of mass of large elements in colors 1–3.

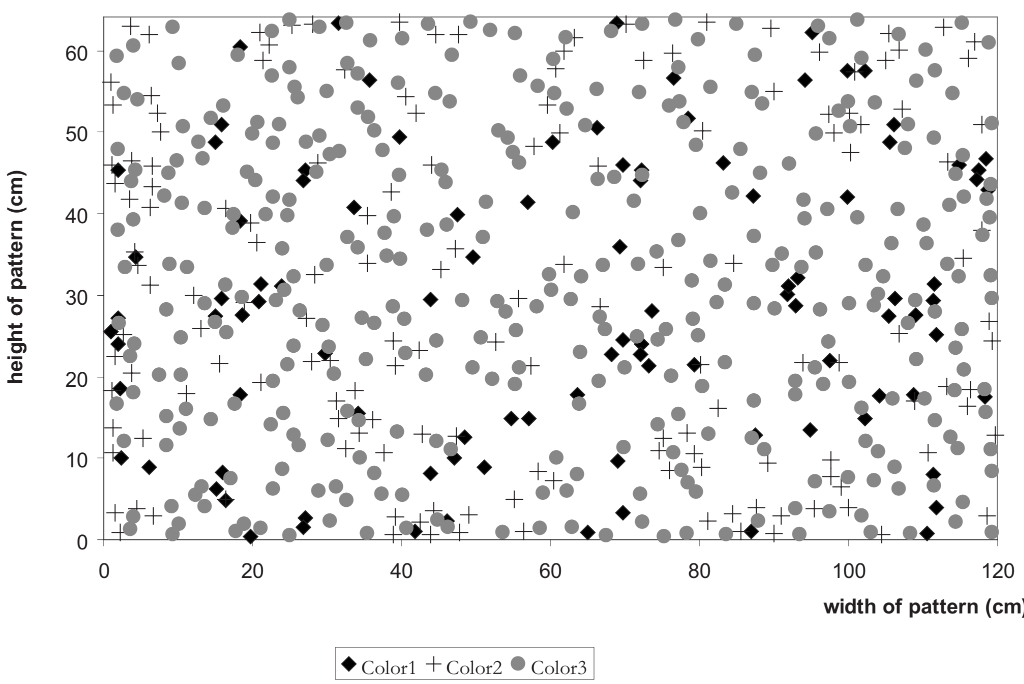


Figure 7. *x* and *y* coordinates of centers of mass of medium-size elements in colors 1–3.

(a) the limit distance from which the observers recognized the camouflage uniform as a single color surface with complete optical mixing of shapes and colors occurred at 138 m,
(b) recognition of a larger non-uniform surface and undefined shapes occurred first at 85 m,
(c) the distance of recognition of the defined pattern and different shapes on the 3D object was from 51 to 85 m,
(d) the limit distance at which recognition of different colors and shapes of single elements in the pattern occurred was 30 m, and
(e) recognition of shape properties, their contours and finest details in the pattern (including, microelements) occurred below 30 m with the limit distance of 14 m.

These results show that as the observation distance increases, the difference between the two limit distances, at which shape, pattern, or color of the pattern was recognized

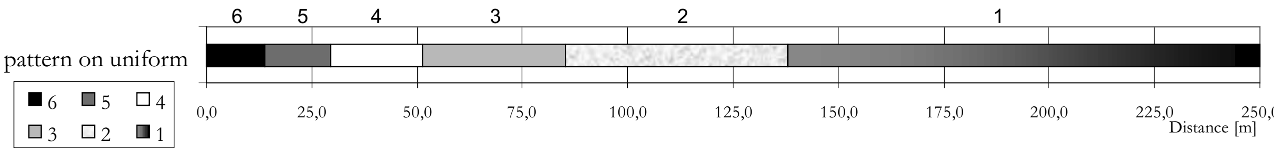


Figure 8. Visual assessment of urban pattern on a camouflage military uniform.

first and last, increases as well. Due to the subjective comprehension of the defined tasks of visual assessment, individuals gave their evaluations at very different distances. The differences in distances of recognition are also a consequence of different visual tolerance of observers, whose visual abilities differ more at longer observation distances. Nevertheless, recognition of the defined pattern and different shapes on the object occurred at planned limit values of detection, which proved also the technical suitability of the camouflage pattern. The Slovenian Ministry of Defense approved the design, which met the requirements for the new urban camouflage pattern.

CONCLUSION

The techniques for composition and design of camouflage patterns originate in art and artistic principles. With the development of science and technology, these techniques became more science-focused, including computer art and technology, mathematical algorithms, accurate study of optical and visual effects of patterns at certain observation distances, morphological analysis of a particular environment, and functions of defined properties of camouflage patterns in a predefined environment.

The purpose of the research presented here was to design an urban camouflage pattern, the detection and recognition properties of which would work well in different target areas in the heterogeneous Slovenian urban environment. Therefore, the use of a computer-based mathematical definition of a camouflage pattern from selected digital images was not appropriate for the research. Instead, the research offers different principles and methods to achieve camouflage effects of an urban pattern in the Slovenian urban environment, i.e., processing of digital images, visual characterizations and grouping of shapes and repeats, morphological analysis of urban environment, image, shapes, and repeats analysis, visual recognition, and pattern detection. The advantage of these methods is that in the sense of modeling and design the presented pattern retains its textile aesthetics, but is upgraded with principles and methods providing defined camouflage, optical, and technical properties.

With regard to the shape and repeats analysis of digital images, their classification and visual evaluation took place in different parts of the urban environment. Moreover, the image elements included in the pattern are representative of a heterogeneous urban area—Slovenian cities, more precisely. At this point it needs to be stressed that one of the most significant requirements by the Ministry of Defense was that the pattern be representative of the nation, since every NATO-member country needs to represent itself through typical military uniforms for different areas in the environment. Moreover, in the research, special attention was given to the image and visual analysis of the pattern, which both confirmed pattern adequateness considering the requirements of the Slovenian Army. The evidence for technical suitability of the pattern is visual tests which confirmed that a human body dressed in the resulting camouflage uniform is difficult to detect, and shapes and the pattern are unrecognizable at required observation distances. Consequently, the presented camouflage pattern was approved for printing and manufacture to cover the needs of the entire Slovenian Army for new camouflage uniforms with an urban camouflage pattern.

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