Original Article

On the Possibilities of using Some Modern Three-dimensional Modeling Means in Forensic Examination

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Abstract

Background: The paper examines the state and prospects of using 3D modeling in solving identification, classification, diagnostic and situational tasks of forensic examination. **Aims and Objectives:** The aim of this study is to analyze the world expert practice of using scientific and technical means of three-dimensional modeling in solving problems of forensic examination, using the example of our country, the leading countries of Europe, as well as the United States. Materials and Methods: The empirical basis of the study is the results of the systematization of scientific and technical means for 3D modeling in solving identification, classification, diagnostic and situational problems of forensic examinations used in the expert practice of Ukraine, the United Kingdom, France, Germany, and the USA. **Results:** The systematization of modern scientific and technical means for 3D modeling, used in solving identification, classification, diagnostic and situational tasks of forensic examination, has been carried out. We analyzed and identified 3D modeling software that most fully meets the requirements of effective forensic expert activities. The features of the use of effective 3D modeling mean for solving identification, classification, diagnostic and situational tasks of forensic examination, namely the software systems "ToolScan" and "TrasoScan", and the SketchUp program have been disclosed. **Conclusion:** The introduction of the SketchUp 8 software into forensic expert activities will increase the effectiveness of the modeling method in forensic examinations, which, in turn, will have an impact on the effectiveness of expert conclusions, increase their evidentiary value and, as a result, contribute to the entire process of a criminal investigation.

Keywords: Classification tasks, diagnostic tasks, forensic practice, identification tasks, photogrammetric modeling, simulation modeling, three-dimensional model

Introduction

One of the underestimated, potential, and promising methods of examining physical evidence during forensic examinations is modeling. In addition, modeling seems to be a fairly universal research method, which confirms its use in solving the entire range of tasks of forensic examination: identification, classification, and diagnostic. The value of this method has been repeatedly emphasized by forensic scientists and also practically proven by forensic experts in the process of conducting examinations.

However, the use of modeling in solving identification, classification, and diagnostic problems of forensic examination is impossible without effective, reliable, proven, innovative scientific and technical means, which are an effective indicator of the functioning "mechanism" of the modeling method.[1] Hence, scientific and technical means can be used both in the detection, fixation, and seizure of forensic evidence, when the models are built and preliminarily studied, during investigative (search) operations, especially when examining the accident scenes, and at the stages of separate research and forensic examinations tested by experts.

Although even having a detailed algorithm of the modeling method, knowing all the scientific and theoretical principles of its application, the result can be negative if you use an incorrectly

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selected, outdated, low-quality or untested tool. In turn, the features of modeling mean directly depend on the purpose of using the method, the properties of research objects, the ability to apply it, etc., The identified problems of using modeling mean in forensic examination requires the implementation of innovative scientific and technical means into expert practice, especially when solving situational problems in conditions of complex structures and results of criminal activity.[2]

At present, one of the promising directions for the development of innovative modeling technologies is the construction and study of a simulated virtual three-dimensional (3D) space, which resembles the original object as much as possible, with the aim of further researching, or as it is called 3D modeling. At the same time, the adaptation of innovative modeling means must meet certain criteria, namely availability, efficiency, versatility, timeliness, and economic feasibility.[3,4]

Availability should reflect the possibility of effectively solving the problems of forensic examination using scientific and technical modeling means by an expert independently, without contacting a relevant developer or user specialist.[5] Efficiency presupposes obtaining sufficiently high results when using this or that means. The versatility provides for the possibility of using this modeling means in solving a wide range of tasks by forensic science experts, as well as by an investigator when inspecting accident scenes and some other investigative (search) operations. The timeliness criterion provides for the allocation of optimal time for the use of modeling means in the conduct of forensic examination, which, on the one hand, corresponds to the effective solution of problems, and on the other hand, to the terms established by law. Moreover, the last criterion, economic feasibility, reflects a fairly minimal cost of a modeling means that does not affect its effectiveness.[6,7]

Unfortunately, when solving a number of problems of forensic examinations, methodological recommendations regarding the choice and use of 3D modeling means continue to be general in nature, and in most cases, the effectiveness of 3D modeling continues to depend on the knowledge and experience of a particular expert, as well as his technical equipment and knowledge of computer.[8] That is, there is a discrepancy with the above criteria for the effective use of 3D modeling in forensic expert activities.

The purpose of this study is to analyze the world expert practice of using scientific and technical means of 3D modeling in solving problems of forensic examination, using the example of our country, the leading countries of Europe, as well as the United States; to identify the advantages and disadvantages in the use of certain means, as well as establishing and substantiation of the most effective software tools of 3D modeling, with the development of proposals for their use in forensic examination.

Literature review

3D modeling, the process of creating a 3D model of an object, is carried out using special software. An analysis of scientific literature and modern forensic practice of Ukraine, the United Kingdom, France, Germany, and the United States has established that at present, the software for 3D modeling in expert activities, depending on the tasks set, are divided into two groups: photogrammetry and simulation.[9-11]

E. Bostanci[10] believes that photogrammetry software is a kind of graphic, but with the ability to build an accurate 3D model with photographic images, or as a result of using a laser scanner. In this case, photogrammetric models can reflect both individual objects and a certain situation. Afonin[12] indicates that photogrammetric modeling is aimed primarily at fixing the research object and is used in cases where the latter represents the accident scene or has a complex or unstable structure in time, which does not allow studying the original object directly. According to Osborne *et al*.,[11] simulation means enable you to build a dynamic 3D model of a certain situation, using the initial data, that is, to conduct an experiment to test one of the versions of the mechanism of committing a crime or its elements.

Hence, today, the main photogrammetry software used by modern expert practice include PC-Rect, PhotoModeler Pro 5, Iwitness. The listed photogrammetry software allows you to convert photographs of accident scenes into a plan (top view) and then into a large-scale "diagram" (graphic drawing). However, the principle of converting photographs into a plan (diagram), which is the basis for the operation of software products, without additional verification of the distances indicated on the "final" diagram, may cast doubt on the accuracy and reliability of the document.[13] Thus, the question of the possibility of drawing up a detailed large-scale scheme at the scene of accidents still remains unresolved.

There are graphic programs for drawing up only a large-scale scheme at the scene of traffic accidents. In this regard, a set of software under the general name "computer-aided design (CAD) Zone" certainly deserves attention. "CAD Zone" is a software package developed in the USA for police officers, which includes the following programs: "Fire Zone," "Crime Zone," "Crash Zone," "Quick Scene," and others. The first graphic creation programs for the US police began to be introduced into practice in 1990.[14]

There are graphic programs for drawing up only a large-scale scheme at the scene of traffic accidents such as "CAD Zone." "CAD Zone" is a software package developed in the USA for police officers, which includes the following programs: "Fire Zone," "Crime Zone," "Crash Zone," "Quick Scene," and others.[14] The Crash Zone program is designed specifically for use by police officers who document road traffic accidents. Qian *et al*.[14] believe that the main features of the program are the ability to collect data from previous "diagrams" and significant reduction in the time for creating new drawings.

Leipner *et al*.[15] point out that the police departments of the USA and Canada have also long and successfully used such

a program of capturing the circumstances of the accident as "Quick Scene." The mentioned software in the police car allows you to create a diagram of the situation at the scene. Despite the fact that "Quick Scene" is a simpler version of the "Crash Zone" program, it is a very powerful "tool" that includes a wide range of possibilities that enable you not only to draw roads and intersections, put text and measurements into a "diagram," but also, in the latest version of "Quick Scene," you can turn two-dimensional (2D) images into 3D.[15] The drawing program "Quick Scene" makes it possible to visually control the measurements and eliminate the probability of "gaps" in the "diagram." It is used in patrol cars to create a general "map" of accident sites, including road traffic accidents and download data from the scene to the stationary computer of the police department for further work.

Special attention should be paid to simulation programs ("PC-Crash," "Carat-3," "Analyzer Pro," "Cyborg Idea V-Sim"), which consider a wide range of parameters and reproduce (simulate) in dynamics the mechanism of movement and interaction of various research objects (transport, people, etc.). In practice, the use of these scientific and technical means is possible only after analyzing all the materials collected upon the accident. Perlin *et al*. note that the "Carat-3" program is now used in the regional divisions of the expert service of the Ministry of Internal Affairs of Ukraine and allows considering the movement of objects in kinematic and dynamic modes and calculating vehicle collisions in road traffic accidents. An important advantage of the program is the ability to determine the speed of vehicles before a collision (by modeling) from the known initial data.[9] However, the use of simulation software by forensic experts remains problematic due to the poor-quality designed materials of the inspection of the accident sites.

By analyzing the scientific literature and modern forensic practice in Ukraine, the United Kingdom, France, Germany, and the United States, we[12] systematized the scientific and technical means of 3D modeling used in solving identification, classification, diagnostic and situational tasks of forensic examinations, namely.

Photogrammetric

Fixation means

Laser scanners such as "Z + F IMAGER 5006" (Germany), "Riegl" (Austria), "FARO Focus3D 120" (USA), and others.

Means of fixation and subsequent computer processing

Software packages that allow to build 3D-models: "PC-Rect," "PhotoModeler Pro 5," "Iwitness" (used mainly in transport and trace evidence analysis);

Graphic software package for drawing up large-scale diagrams "CAD Zone:" ("Fire Zone," "Crime Zone," "Crash Zone," "Quick Scene," and etc.);

Simulation

- Software package "PC-Crash"
- Software package "Carat-3"
- Software package "Analyzer Pro"
- Software package "Cyborg Idea V-Sim" and others.

The main disadvantages of the used scientific and technical means of 3D modeling are inconsistencies with a number of the above criteria (accessibility, efficiency, versatility, timeliness, and economic feasibility). The most significant disadvantages are the complexity of using these software packages that require special training for an advanced user; narrow focus (nonuniversality) in solving a number of tasks of forensic examinations; partial functional obsolescence of these software packages.

Methodological Framework

In the study, a range of general scientific and special methods was used to achieve this goal. Thus, the methodological basis of the study is the dialectical method of scientific knowledge, which allowed us to consider the theoretical and scientific-practical foundations of the modeling method in forensic examination and identify innovative modeling means. On this methodological foundation, special scientific methods of cognition were also used in the research. Hence, with the help of chronological and comparative-historical methods, the reasons that prompted the need for the search, implementation, and development of new scientific and technical modeling means in forensic examination have been analyzed. Based on the identified promising areas of modeling, considering the development of scientific and technological progress and the introduction of innovative technologies in forensic expert activities, the most effective means are scientific and technical modeling means in forensic examination.

Using the logical-semantic method, we studied the general scientific meanings of such concepts as "3D modeling," "3D model," "photogrammetric modeling," "simulation modeling," "3D scanning," "3D visualization," "3D comparisons," and others. We analyzed the content of a number of definitions and determinate their significance within the framework of the study. When analyzing trends in society with regard to increasing interest in certain new 3D modeling means and the possibility of using them in solving problems of forensic examinations, we used methods of sociological research and expert assessments.

The system-functional method was used to determine the group and species characteristics of the considered scientific and technical 3D modeling means. Comparative methodological approach was applied to identify common patterns in various methods of using scientific and technical means for 3D modeling, search for such tools that meet the criteria for the effectiveness of their use, by analyzing the modern expert practice of Ukraine, the United Kingdom, France, Germany, and the United States and to determine the practical effectiveness of new 3D modeling means.

Using the structural-logical method, the most effective means for 3D modeling in solving problems of forensic

examinations have been substantiated. The necessity of their implementation is justified. The problematic issues of their implementation are identified, while the directions of their solutions are proposed. We used predictive methods to identify the most promising 3D modeling means and the possibility of using them in solving problems of forensic examinations.

The theoretical framework of the research study is the work of modern scientists from leading European countries and the United States in the field of forensic science, cybernetics, mathematics, and other sciences. The empirical basis of the study is the results of systematization of scientific and technical means for 3D modeling in solving identification, classification, diagnostic and situational problems of forensic examinations used in the expert practice of Ukraine, the United Kingdom, France, Germany, and the USA.

Results and Discussion

Since 70s of the 20th century, scholars began to develop and implement computer modeling in various spheres of human activity, but its use for a long time, up to the 90s of the 20th century, remained the prerogative of programmers, and therefore its implementation in forensic expert activities remained problematic.[16] Thanks to the positive dynamics in the development of innovative technologies since the 90s of the 20th century, investigators, detectives, forensic medical experts, ballista experts, and other forensic specialists from leading foreign countries (USA, UK, France, etc.) have begun to introduce 3D modeling software into practice in the investigation of criminal offenses.[17] However, the modeling means in forensic examinations reached a fairly complete compliance with the above criteria at the end of the first decade of this century.

Thus, systems for a comprehensive study of the surface morphology "tool scan" and "TrasoScan" are widely used in solving identification and diagnostic problems by forensic experts in the performance of fingerprint, trace evidence analysis, and ballistic examinations. The capabilities of these systems are not limited in their functionality, like existing standard comparative microscopes, but, on the contrary, are expanded to the ability to create 3D models. LuciaToolScan allows you to scan and visualize 3D structures down to the smallest detail. In the LuciaToolScan system, a wide range of tools is available to fixate positions of different details, even complex ones, for example, you can place the lock core using a special holder. In addition to standard measurements, image processing tools and Z-profile measurement, LuciaToolScan offers several 2D and 3D comparison tools. In 3D mode, objects can be positioned opposite to each other or, in semi-transparent blending mode, freely rotated along three axes.[18,19] The main features of the ToolScan and TrasoScan systems are top-class telecentric optics; resolution 3 μm per pixel; magnification up to 80x; wide stage and automatic focusing; the image is displayed on the monitor in real time; 3D scanning, 3D visualization, 3D comparisons; nonembossed image mode of the "digital silicon casting" type; integration of part management software to take full advantage of the measurement capabilities of instruments with annotation and image processing.

Furthermore, now, the police units of developed European countries (the United Kingdom, France, Germany) and the United States use modern technologies and devices to reduce the examination time and create an objective digital model of the accident scene–laser scanners.[10] Laser scanning is widely used to document the situation at an accident scene of all types of accidents (including road traffic accidents). Particularly, relevant is the combined use of laser scanners and high-resolution digital cameras, which makes it possible to "colorize" scans in true color and obtain an orthophoto for detailed and accurate measurements. Obtaining the exact dimensional measurements at the accident scenes with classic photographic images is a rather complicated process and is not always possible (requiring a thorough analysis of the shooting site). Laser scanning technology, on the other hand, provides an opportunity to give a measurement based directly on the point cloud (each point has its own unique set of coordinates X, Y, Z) and thus to obtain the dimensional measurements of all visible objects of the "crime scene." By means of laser scanning, the required number of scans are received, which are combined into a complete image of the scene. This data can be saved to any electronic storage device for later use.

The laser scanning data enables you to make all the necessary measurements of all the most important elements of the "crime scene" at any time without the need for a new data collection. The 3D "scene" retains the situation occurred when capturing the accident scene. The laser scanner software is able not only to visualize 3D images of the "crime scene" but also to change the position of its observation points in an arbitrary manner. In contrast to photographic methods, in which forensic specialists take photographs selectively, relying on their own vision of the situation at the accident scene, the laser scanning method assumes full coverage of the entire crime scene without gaps and allows you to reconstruct the picture of the accident at any time.

However, one of the effective means for 3D modeling is the SketchUp program, which meets all of the above criteria (accessibility, efficiency, versatility, timeliness, and economic feasibility), in this regard, we will consider it in more detail. SketchUp is primarily a photogrammetry software tool for constructing accident scene models with a wide range of trace information, some elements of which may be missed by an investigator, a forensic specialist during the examination. However, the program can be used to build simple animation by fixing certain camera angles to the model and then sequentially scrolling through these images. In this connection, it is possible to build a model not only of the accident scene with the whole complex of traces and other material evidence, but also, for example, the possible movement of the criminal at the accident scene.

The SketchUp program (version 8) was tested in forensic expert activities, namely in solving diagnostic and situational problems of trace evidence analysis and fingerprint examinations. The use of this program in 2018-2020 by forensic experts of the Odessa Scientific Research Forensic Center of the Ministry of Internal Affairs of Ukraine has shown good results in establishing the localization of traces of both homoscopic (human traces) and mechanoscopic (traces of instruments and tools) origin, as well as spatio-temporal and cause-effect relationships between objects of marking formation on stages of separate research, forensic examinations tested by experts and fingerprint examinations.[12]

Before moving on to an example of how to build a 3D model in SketchUp, you need to pay attention to the basic rules of its use. When starting SketchUp, the user is given the option to select a project template. SketchUp templates do not limit its capabilities. They provide the ability to customize certain parameters (color, background, scale, etc.), so that they no longer have to be selected when building the next models. At the same time, it is possible, if necessary, to configure these parameters in the template after the creation of the project. In the parameters, it is possible to configure measurements with both metric and imperial (used in the United Kingdom) systems. When creating a new project, the user is given a window with three axes: X, Y, and Z, according to the Cartesian coordinate system. Each axis has its own color: X-red, Y-green, and Z-blue. Each of the axes consists of solid and dashed lines. The solid line defines the front, and the dotted line defines the rear. This is done to aid in orientation when observing a 3D object in projection, especially when moving a virtual camera around an object (for example, a model of an accident scene).

SketchUp has a very extensive set of ready-made models. Models are simple virtual 3D objects that are created by the developer of the program but can be created by the user as well. They are divided into general and special. General models are furniture, walls, doors, windows, etc., and special ones are burglary tools, weapons, footprints, corpses, and the like.[20] The peculiarity of all models is that with the help of the camera, they can be viewed from any angle.[21] One of the complexes but very important models in criminalistics and forensic examination is the human corpse model. The difficulty consists in the fact of lying out the corpse (position of the arms, legs, head, etc.), i.e., it should look like the original object.[22] In this case, there are two possible solutions to the problem. First, to use another software such as Smith Mirco's Poser to build a model and then import the entire accident scene into SketchUp. Second, to use the 3D Warehouse database of human bodies in various poses and also import into the main accident scene model in SketchUp. If the model of the corpse needs to be finalized (laid out it a more precise position), then we recommend loading the model into a separate SketchUp file and using the control points that correspond to the position of the human joints, bring the positions of the individual parts to the required position, and then add them to the main model of the scene.

SketchUp also provides tools for panning, zooming, and moving the research object model. These tools are especially useful when building accident site models. In addition, the camera has seven standard positions, which make it possible to quickly place the camera relative to the coordinate axes and the center of the model of the research object. Another important aspect of viewing the model of the research object is the camera projection. Thus, three different camera projections are available: parallel projection, perspective, and 3D projection. It is also possible to create your own camera fix position using the Scene Manager window. You can create special tabs for the camera position in the upper corner of the window, which will allow you to quickly select the desired position. In addition, the created models of individual elements of the research object can be renamed, rearranged, or even deleted. Moreover, they can be exported to flat images or animations (live images). A useful tool in building and researching a model of a research object is to change the required visual style. The visual style of a model has an impact on its perspective, transparency, and other features. Styles create actualization for certain things in the model, simplifies its viewing, especially when showing (presenting) it to the initiator of the forensic examination. A very important tool in SketchUp is the ability to create layers. This tool is also used to draw attention to certain elements for the purpose of their presentation, editing, and vice versa-hiding to preserve them.[20] For example, one layer can include all furniture that can be hidden to revise the floor plan; traces of a certain type (fingerprint) or those that relate only to the criminal for the purpose of working out the expert version.

Let us consider the basic SketchUp tools that the expert needs when modeling complex objects and situations during identification, classification, diagnostic and situational forensic examinations.

1. Tool palette "Large Tool Set" gives a wide selection of colors and shades for models. In addition, it is possible to load chosen or created palette into the database
2. Tools "Line," "Arc," and "Freehand" enable you to draw 2D lines. The "Line" tool is used to draw a line, but with the ability to control its length according to the scale. The Arc tool lets you draw arcs with control over the number of arc bulges. The Freehand tool makes it possible to freely draw any shape you like. There is also a set of drawing simple shapes circles, rectangles, triangles, etc
3. Tool "Push/Pull" allows the user to convert flat images into 3D models. At the same time, you can adjust the required sizes and adjust the shape of the model
4. The "Offset" tool is considered to be especially useful when placing individual elements of the accident scene model. Hence, when loading a flat diagram of the accident scene, the user transfers control points from the diagram to the 3D model, as it were, by step-by-step selection of them on the diagram and model
5. Tools "Move" and "Rotate" allow you to move and rotate both flat images and 3D models in any direction

6. Tools "Orbit" and "Pan" are similar to the previous ones but have some movement fixation. Hence, with the help of "Orbit," you can rotate a model like a globe, and "Pan" lifts the camera and moves it without rotation
7. Tool "Scale tool" provides the ability to display the sizes of the models (1/64 inch or 0.039687 cm) with a sufficiently high accuracy
8. Tool "Tape Measure" and "Protractor" allow you to make measurements of distances and angles
9. Tool "Text" and "3D Text" provides an opportunity to make the necessary designations of individual elements of the accident scene model
10. Tool "Paint Bucket" allows you to select and apply the structure of any material (various types of wood, metal, textiles, vegetation, etc.). Furthermore, like the previous base models, you can download them from the database or create personally.

The important thing about working with SketchUp when building models in forensic research are the use of plugins. These are compiled additional software modules that allow you to expand the program's capabilities. Hence, for example, the plug-in "Advanced Camera Tools" created for SketchUp Pro enables you to improve camera control, namely it opens the ability to adjust the focal length and other camera parameters. The CubicPanoOut plugin is a special software module that works in conjunction with the panoramic image converter and makes it possible to create virtual 3D panoramic tours in a SketchUp model. Hence, an expert, using VR-glasses, can "walk" on a virtual scene model, examining it, demonstrate it to the investigator, paying attention to certain traces, and so on.

Furthermore, the compilation of the model measurement tables is important in using SketchUp modeling in forensic science. Adding such measurement tables will provide the initiator of the examination with confirmation of the accuracy of the model, that is, its compliance with the real object. Table data are formed on the basis of indicators (attributes) and the sizes of individual elements (length, width, height, angle at which the object is placed, etc.). It is also possible to specify the name of each row and column in the table. The table can be stored as an HTML file suitable for viewing in an Internet browser, or in a file format of the SketchUp program itself (extension "csv"), which can be viewed in Microsoft Excel or LibreOfficeCalc software.

Conclusion

Based on the foregoing, it can be stated that the practice of using 3D modeling in forensic examinations requires further in-depth study and implementation of modern innovative technologies aimed at building and researching 3D models in a "virtual" space using photogrammetry ("ToolScan," "TrasoScan," "PC-Rect," "PhotoModeler Pro 5," "Iwitness" and others) and simulation ("PC-Crash," "Carat-3," "Analyzer Pro," "Cyborg Idea V-Sim," and others) software. This will contribute to the effectiveness of the application of the modeling method in forensic examinations and will have an impact on their evidentiary value.

However, at the moment, the SketchUp software tool (version 8) is the most effective, versatile, and economical means of building accurate 3D models of the accident scene, a corpse, a criminal offense weapon, material traces, etc., based on the data recorded in the accident site inspection protocols, plan-diagrams and illustrative photo tables, which provides a wide range of solutions to problems of identification, classification, diagnostic and especially situational nature in forensic examinations. The effectiveness of the SketchUp program (version 8) was confirmed by testing it in 2018–2020 by forensic experts of the Odessa Research Forensic Center of the Ministry of Internal Affairs of Ukraine in establishing the localization of traces of both homoscopic (human traces) and mechanoscopic (traces of instruments and tools) origin, as well as spatio-temporal and cause-effect relationships between objects of marking formation.

The introduction of the SketchUp 8 software into forensic expert activities will increase the effectiveness of the modeling method in forensic examinations, which, in turn, will have an impact on the effectiveness of expert conclusions, increase their evidentiary value and, as a result, contribute to the entire process of criminal investigation.

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Conflicts of interest

There are no conflicts of interest.

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