

## USE OF COMPUTER SIMULATION IN FORENSIC BIOMECHANICS

### UTILIZAÇÃO DA SIMULAÇÃO COMPUTACIONAL EM BIOMECÂNICA FORENSE

Article received on: 10/2/2025

Article accepted on: 1/2/2026

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The authors declare that there is no conflict of interest

#### Abstract

The article deals with a criminalistic experiment and the possibility of using computer modeling. The paper describes the current possibilities of using computer simulation and presents the possibility of using it in clarifying versions in the case of a specific crime. A promising method is the Virtual Crash 3 program. This is certified software that was developed for forensic engineering and biomechanical applications. This method makes it possible to simulate situations that cannot be practically realized by a real experiment with a mannequin or a living person. The paper presents one specific example. Computer simulation of human movement can very accurately clarify the probability of individual versions when assessing a person's fall from a height.

**Keywords:** Experiment. Biomechanics. Criminalistics. Computer Simulation.

#### Resumo

*O artigo aborda um experimento criminalístico e a possibilidade de utilização de modelagem computacional. O texto descreve as possibilidades atuais de utilização da simulação computacional e apresenta a possibilidade de seu uso para esclarecer versões em casos de crimes específicos. Um método promissor é o programa Virtual Crash 3. Trata-se de um software certificado, desenvolvido para aplicações em engenharia forense e biomecânica. Esse método permite simular situações que não podem ser realizadas na prática por meio de um experimento real com um manequim ou uma pessoa viva. O artigo apresenta um exemplo específico. A simulação computacional do movimento humano pode esclarecer com grande precisão a probabilidade de diferentes versões ao avaliar a queda de uma pessoa de uma altura.*

**Palavras-chave:** Experimento. Biomecânica. Criminalística. Simulação Computacional.

## 1 INTRODUCTION

Clarification and investigation of criminal activity brings with it moments when it is necessary to verify certain hypotheses that are associated with the emergence of traces or the emergence of information in them. [1] It happens that criminologists need to verify doubts about the possibility or non-performance of a certain activity of the perpetrator, the possibility or impossibility of the existence of a certain event, phenomenon, event or activities associated with a criminologically relevant event. For this process of knowledge, criminological science uses a criminological experiment as one of the criminological-tactical methods.



A criminological experiment is a method of criminological practical activity, consisting in the experimental invocation and examination of criminologically relevant phenomena, activities and fragments of events in artificially created and purposefully changed conditions for the purpose of knowing and proving the facts of the case. The aim of a criminological experiment is also to verify versions.

It is checked which of the versions is true, which at the same time eliminates unrealistic versions. For checking versions, a forensic experiment is suitable for a wide range of experimentation possibilities, changing conditions during its course and for the possibility of repeating individual experiments.

The essence of a forensic experiment is based on the method of experimentation (as a means of knowledge) - a method of investigation in which, through a certain systematic action on the processes of objective reality, we obtain new knowledge.

The method of forensic experiment can be viewed both as a special method of forensic practice and as a specific method of forensic practice. As a specific method of forensic practice, a forensic experiment is applied in the process of knowing a crime in the form of an investigative act under the name of an investigative experiment having the nature of an independent means of evidence.

One of the forms of a forensic experiment is an expert experiment. It is usually carried out by an expert as part of an expert examination, and the results of the experiment are reflected in the conclusions of the expert assessment. At the current level of knowledge, an expert experiment can be carried out in the form of a computer simulation.

## **2 POSSIBILITIES OF COMPUTER SIMULATION OF HUMAN MOVEMENT FOR THE NEEDS OF FORENSIC BIOMECHANICS**

Biomechanical analysis plays an important role in cases of explaining falls from a height. The main task of the expert is to help clarify whether the fall was caused by accident, suicidal action or the fault of another person. The purpose of experiments and modeling is, for example, in the case of a murder committed by throwing the victim out of a window, to illustrate the position of the victim and the perpetrator at the decisive moment, the behavior of the body during the fall, the probable place of impact, even in the case of a murder, suicide or unfortunate accident version. In forensic practice, a

forensic experiment is carried out by "playing out" individual execution variants, varying the possibilities and assessing the results. During the experiment, the participant repeats individual movement activities, or a suitable dummy is used.

The development of computer technology has brought a very positive shift in the quality of forensic experiments and modeling of situations. Criminalists have started to use a graphical computer method from three-dimensional dimensions, especially in murders committed with firearms, throwing victims out of windows, suicidal jumps from windows or unfortunate falls from heights.

In addition to classic criminalistic tactical methods, such as criminalistic experiments, computer simulation is gaining importance. From the perspective of forensic biomechanics, it means determining the kinematic and dynamic parameters describing the movement and interaction of the human body with other objects at the scene of the crime. All this in accordance with the available evidence and statements of witnesses, victims or suspects.

The typical reconstruction procedure is retrospective, i.e. we know the final state of the event and from the available evidence we try to determine the initial state and its changes over time until we reach the state known to us. In the case of a fall from a height, there is no general unambiguous relationship between the initial conditions of the fall and the final position of the victim, and the final position can be achieved from various input conditions [3].

Computer modeling is needed especially in cases where it is necessary to clarify possible or impossible variants of a movement activity. Forensic methods allow us to express our opinion on the question of whether a given movement activity is biomechanically acceptable or unacceptable. It is also possible to express our opinion through computer modeling of movement, which of the variants is more probable [4].

In recent years, the literature has presented the possibilities of computer simulation, some authors use the PC Crash, MADYMO, PAM-Crash or Virtual Crash models, recently the Virthuman simulation program has been used [4].

Due to the development of science and technology, the finite element method and multi-body systems appear to be a refinement of the models used for the needs of forensic biomechanics. The finite element method allows solving biomechanical problems,

including the issue of deformation of individual bodies. The finite element method is used, for example, by the PAM-Crash, MADYMO or Virthuman programs. The financial cost of acquiring these highly professional programs and the time-consuming nature of the calculation put them in the position of programs that can only be used exceptionally in specialized workplaces. For routine calculations for the needs of forensic biomechanics, their practical use is unthinkable.

A multi-body system is defined by only a few rigid bodies connected to each other by articulated constraints. This approach does not provide the possibility of deformation, but its advantage is a short calculation time and high accuracy and clarity of the simulation.

It is appropriate to apply Virtual Crash and PC Crash to solve the problem of forensic biomechanics. In the basic information on the use of the computer simulation Virtual Crash, an example of solving the motion situation of a person falling on stairs can be found [5]. The documentation clearly states that Virtual Crash is a very suitable software tool for accident reconstruction, pedestrian impacts, bicycle impacts and other biomechanical reconstructions.

The literature describes a case of a man falling over the edge of a railing and the subsequent cascading fall from the third floor to the floor, the case was analyzed as a detailed study using the computer simulation PC Crash. A number of simulations were performed using PC Crash, which made it possible to determine the boundary conditions. It was shown that this simulation can bring valuable information for revealing the mechanism of the fall and verifying various hypotheses.

Recently, a new simulation program Virthuman has appeared. Virthuman is a model of the human body based on the MBS (Multi Body Structure) approach. The model consists of movable rigid segments that represent the correct mass of each human part and allow the evaluation of damage criteria describing safety risks during crash scenarios. The Virthuman model was developed to assess safety risks in various complex collision scenarios, including impacts from different directions. The individual segments, which are connected to the basic skeleton using nonlinear springs representing the behavior of the surrounding soft tissues of the human body. The behavior of individual body segments (head, chest, pelvis, lower limbs) is validated using generally accepted procedures and methodologies. The Virthuman model is designed modularly so that it can be easily

modified for defined parameters of the human body, which are gender, age (6-75 years), height (105-195 cm) and weight.

For forensic biomechanical applications, the use of computer modeling and simulation in the Virtual Crash program is very suitable. It is a fast, affordable software tool for accident reconstruction and solving biomechanical issues. This program can analyze motor vehicle collisions, pedestrian impacts, bicycle impacts, motorcycle impacts, and also perform biomechanical analysis of selected movement situations.

An example of calculating a human body fall with the support of the simulation program documents that with correct input parameters, other movements than those in road accident analysis can be modeled very well with the help of a multi-body system.

The Virtual Crash simulation program is a new generation program primarily intended for technical analysis of road accidents, it is constantly being improved, and newer versions of the simulation program can also be successfully used for solving biomechanical situations. The rapid development of computers and software increasingly allows complex calculations to be performed in real time. The simulation program allows you to display results in 3D views and the outputs can be presented in many diagrams and tables.

### **3 FORENSIC EXPERIMENT AND COMPUTER SIMULATION**

Personally, I believe that the Virtual Crash and PC Crash simulation programs can be successfully used to solve the problem of forensic biomechanics, especially when solving questions about falling from a height. The use of computer simulation provides several advantages, but also disadvantages. On the one hand, it is a relatively fast solution to problems, validated models of vehicles and people, validated kinematic connections between bodies. In addition, it is necessary to be aware that only perfectly rigid bodies can be analyzed, internal active forces (e.g. muscle activity) cannot be introduced into the models, and the relevance of the results is completely dependent on the established input conditions.

A forensic experiment is often used in forensic practice in cases of explaining falls from a height. Let's take into account current forensic practice - when solving the problem of falling from a height, an investigative experiment is often used. The procedure is to

either use a human model (often a rag doll) or create this model. Usually, by stuffing a jumpsuit into the shape and weight of a human body. In such cases, this is a purely lay approach, the human mannequin does not fully correspond to reality. Then, several experiments are carried out, the mannequin is dropped from a given height, and usually the criminologists try to vary the individual versions. These shortcomings can be eliminated by performing a computer simulation within the framework of a criminological experiment.

The possibility of varying movement events with the support of the Virtual Crash simulation program very well replaces the performance of an expert experiment in some cases. Of course, the most appropriate would be to perform an investigative experiment and a simultaneous computer simulation of the event. In such cases, a high degree of certainty of the reality of the observed event is obtained. This will contribute to a high objectification of the investigation and expert assessment.

The very wide complexity of computer programs makes it possible to assess both whether the derived and calculated results are within a technically acceptable range, as well as the technical acceptability of the statements of the individual participants in the accident and compare them with the reality at the scene of the crime. From the documented traces at the scene of the crime, it is possible to very successfully narrow the limits to only technically acceptable solution variants. On the other hand, the minimum of documented forensic evidence does not allow for accurate results for the legal assessment of the case.

I will present a comparison of a forensic experiment with a computer simulation using a specific example.

At the turn of 2013 – 2014, a case was investigated in which a physical fight between three men occurred on New Year's Eve. One of them was stabbed in the stomach and was found dead on the pavement of the yard at around 4:00. Two completely different versions were examined, according to the testimony of the witness and the accused. The witness stated that the attacker stabbed the victim in the stomach, they moved to the balcony and then threw him off the balcony. The accused stated that the victim suddenly jumped through a closed window onto the balcony and then rolled over the edge of the railing and was supposed to commit a suicidal fall. During the investigation, an investigative attempt was carried out. The results of the investigative attempt proved that

one version (the victim's suicidal jump) is an unacceptable variant and, on the contrary, the version of someone else's fault is the real version. In the investigation process, an expert opinion was prepared in the field of criminalistics, specializing in forensic biomechanics, in which a computer simulation with the support of the Virtual Crash 3 program was used. The following figures compare the results of the criminalistic experiment (investigation attempt) (Fig. 1, 2, 3, 4) and the computer simulation (Fig. 5, 6, 7, 8). The following figures show the investigation attempt with a figure (Fig. 3, 4) and the attempt to throw the dummy according to two versions (Fig. 5, 6), as well as the version of the accused E.K. and the version of the witness V.K.

### Figure 1

*Illustration of the variant of pushing in the chest and throwing the injured person over the edge of the railing, according to the version of witness V. K.*



**Figure 2**

*Illustration of a variant of the victim's suicidal behavior, rolling over the edge of the railing, according to the version of witness E. K..*

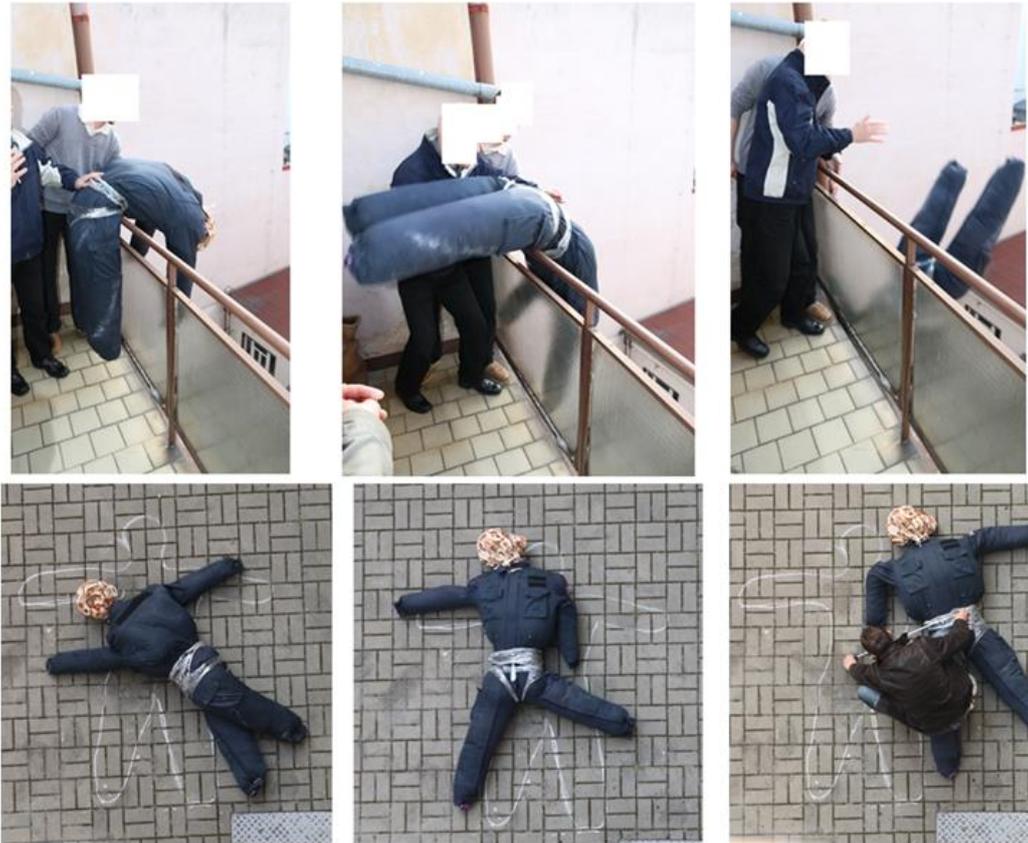
**Figure 3**

*Investigation attempt, photographic documentation of a variant of the "suicidal" jump by rolling over the edge of the balcony railing. Variant according to the version of the accused E. K.*



#### Figure 4

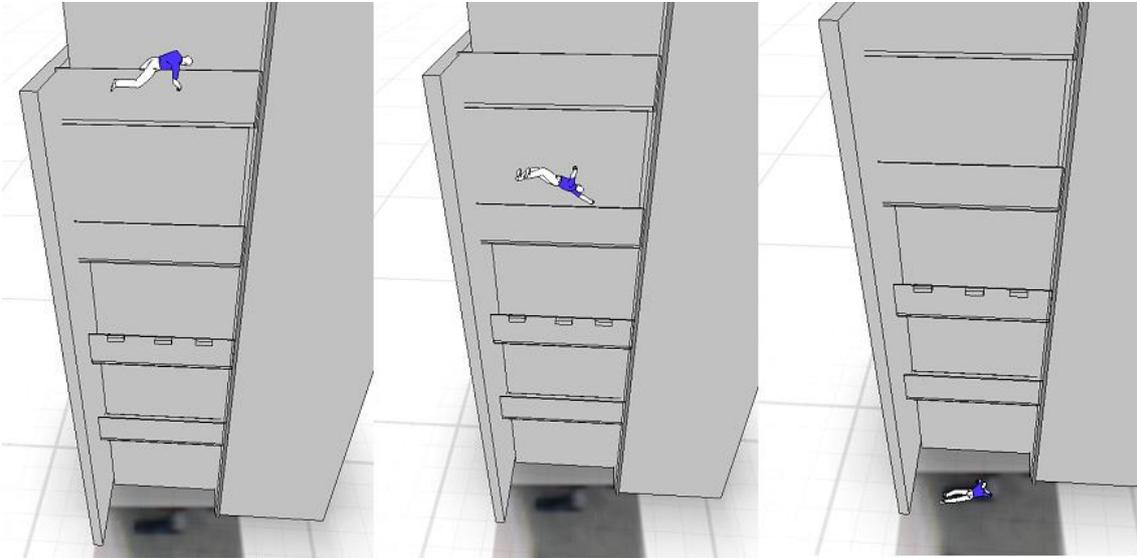
*Investigation attempt, photographic documentation of the variant of actively throwing the dummy over the edge of the balcony railing. Variant according to the version of witness V.K.*



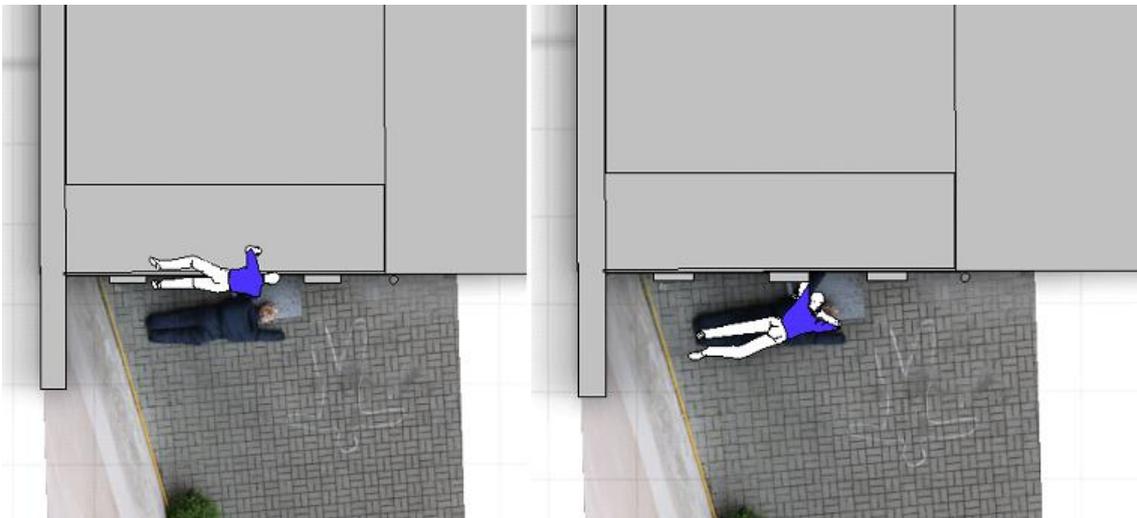
To solve the case, it was also necessary to perform a computer simulation of the individual variants. I simulated both variants in the Virtual Crash3 program and the results are shown in the following figures. Technically acceptable variants of the falls are shown. First is the variant of the injured party falling over the edge of the balcony according to the version of the accused E. K. The second variant presents a technically acceptable variant of the injured party throwing over the edge of the balcony railing, according to the version of the witness V. K.

**Figure 5**

*Technically unacceptable variant of the fall of the injured D. D. according to the version of E. K.*

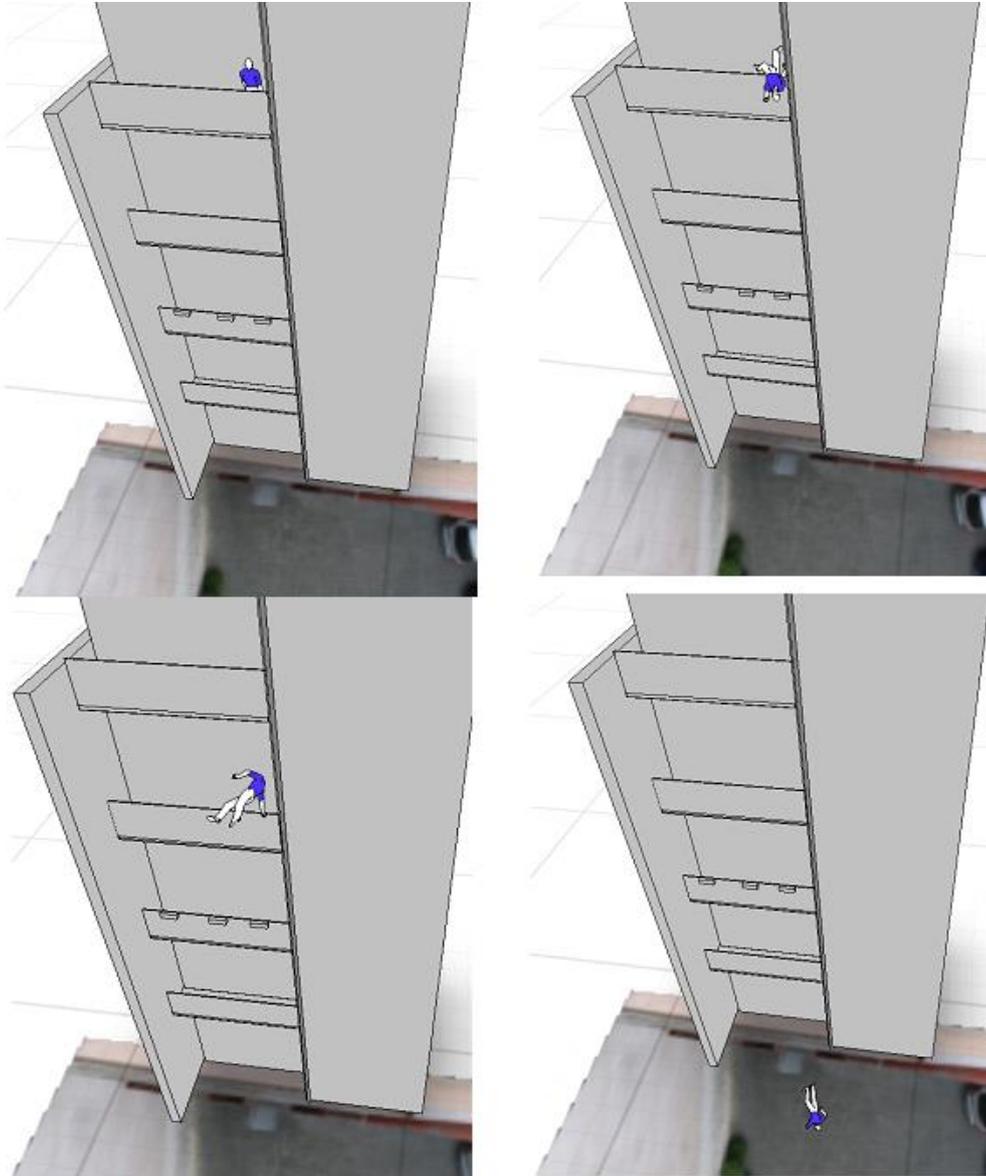
**Figure 6**

*Top view, initial and impact position of the injured party, technically unacceptable variant of the fall of injured party D. D. according to the version of E. K. The position of the victim in the yard was drawn by the outline of the body after the impact.*



**Figure 7**

*Technically acceptable variant of the fall of the injured D. D. according to the version of V. K.*



### Figure 8

*Top view - initial phase of the fall and impact on the ground and final position of D. D. according to V. K.'s version. The victim's position in the yard was drawn by the outline of the body after impact.*



## 4 DISCUSSION

The use of a computer model is advantageous for solving movement situations during criminal investigations in forensic biomechanical applications. The method brings better results than experimental variations with a mannequin. It is possible to simulate a large number of variants in the computer that cannot be implemented in practice. The accuracy of the result depends on the amount of input information and the perfection of the computer simulation.

The use of computer simulation provides several advantages, but also disadvantages. The advantage lies in the relatively fast solution of the task, the simulated situation highly corresponds to reality and the conditions at the crime scene can be reconstructed very accurately. The models of people are validated and they are perfectly rigid bodies. A general problem is the fact that internal active forces, such as muscle activity, cannot be introduced into the models. This is, however, a problem with all existing simulation programs. The main advantage of calculations supported by computer simulation is its objectivity, the quantitative nature of the analysis, high-quality visualization that allows even laymen to quickly understand the problems and, last but not least, the possibility of creating an endless number of variations.

Thanks to both computational and visualization capabilities, even laymen in the field of biomechanics can be given a clear idea of the event, so that they can better

understand the essential circumstances of the case. The input parameter settings can also be easily changed, and the results are then objective in the sense that the movement and interaction are controlled by the laws of mechanics and therefore independent of personal experience or the opinion of the expert. Another great advantage is the ability to provide quantitative data in time, space and even, if the model allows it, dynamic.

Forensic biomechanics methods will use more and more computer simulation capabilities and it turns out that they are a suitable tool for forensic biomechanical applications (especially Virtual Crash 4). These methods are faster, more accurate, cheaper and clearly bring wider possibilities for experimental work. For further use of the presented computer simulation method, it will be appropriate to compare the results of forensic experiments with the results of computer modeling.

## 5 CONCLUSION

In criminology, an experiment is a scientifically justified, procedurally permissible and practically proven method serving as a means of knowing and proving objective truth. Despite some specific elements given by the specific subject of investigation (a criminal event), it retains the basic principles of the scientific experimental method of knowledge.

A criminal experiment is identical in its basic principles to an experiment in any other area of human activity. In a criminal experiment, the body involved in criminal proceedings can itself induce phenomena analogous to the phenomenon being studied, change the conditions under which the phenomenon occurs or isolate individual conditions, demonstrate their priority of significance for the induced phenomenon, etc. . The peculiarities of a criminal experiment can be seen in the fact that the criminal experiment takes place under conditions under which a criminologically relevant event occurred and its results are obvious, registerable by the senses alone, without the need for instruments, complex analysis or special knowledge. The object of the experiment is the individual circumstances of a criminologically significant event (e.g. a crime).

The penetration of science and technology into criminology improves, enhances and accelerates the elucidation of criminal activity. In criminological practice, it often happens that it is necessary to analyze individual real variants of the course of motor

activity. Both figurants and dummies are used. However, this brings complications, very often it is not possible to "act out" the entire event, as stated by individual participants, and thus an interval of movement arises in the motor activity that is indefinite. Individual interested participants may have different opinions and imaginations about it. Even if dummies are used, e.g. when explaining a body falling from a height, imperfections and indefiniteness of the body's movement arise. Computer simulation with appropriate software programs approximates the reality of the event as accurately as possible. All real variants of movement can be varied in the computer and thus express the biomechanical acceptability or unacceptability of human movement. In my opinion, the above simulation program is very suitable for biomechanical modeling of motor action, it allows for a very realistic simulation of human movement.

Computer simulation using human body models provides an explanation for many previously unclear aspects of the case. This method provides objective and quantitative information enabling a much more precise analysis of the studied phenomenon or event – the kinematic and dynamic parameters of the human body and its interaction with surrounding structures. It is even possible to determine the forces acting inside the organism and, thanks to this, to predict trauma more accurately. All important unknown parameters (initial conditions of numerical simulation, such as the position of the body and its individual segments, its orientation in space, initial velocity, etc.) can be parameterized and thus encompass all possible constellations. Another very important advantage of this method is the sophisticated and effective visualization of the calculation results, which makes it easier to understand the studied events and phenomena for judges, prosecutors, lawyers and the police, who do not need to have deep biomechanical knowledge.

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### **Authors' Contribution**

All authors contributed equally to the development of this article.

### **Data availability**

All datasets relevant to this study's findings are fully available within the article.

### **How to cite this article (APA)**

Straus, J. (2026). USE OF COMPUTER SIMULATION IN FORENSIC BIOMECHANICS. *Veredas Do Direito*, 23(4), e234762. <https://doi.org/10.18623/rvd.v23.n4.4762>