

## A MODEL FOR SOLVING STRUCTURAL, TECHNOLOGICAL AND SAFETY PROBLEMS

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**Abstract.** The authors of the present work offer the developed model of suggesting solutions to structural, technological and safety problems based on the use of a tree diagram as a tool for decision analysis and visualization. The model is aimed at integrating solutions worked out in the considered areas into a single variant as a research object. A multi-stage decision model reflecting a set of the available combinations of alternatives is developed. The branches of the tree diagram are interlinked based on the inherent relations between building structures, technologies and work safety. The interaction and interrelationship between the criteria describing the above issues affect each criterion in a very specific way. The performance of the system allows the authors to evaluate the effect of each criterion and its interaction with other criteria, which in turn helps with choosing appropriate solutions to solving structural, technological and safety problems.

**Keywords:** worker safety and health protection, accident, occupational disease, construction sector, sustainable workplace, tree diagram, decision analysis.

### 1. Introduction

A variety of technological processes in modern construction allows for selecting various structural solutions. By using various building materials and working processes, an impressive combination of structural elements may be obtained. The observation of technological development, complex architecture of buildings and their growing height as well as the analysis of the rate of accidents and occupational diseases raise the following questions: Are requirements for safety and health protection always taken into account when technological processes are realized? Is sufficient attention paid to ensuring the safety of the work process? Is human life really valuable?

Highly developed countries pays close attention to working conditions for people. The efforts are made to create the conditions that could not harm human health and would not be dangerous for humans and their lives (Pink *et al.* 2010; Liaudanskiene *et al.* 2009, 2010; Doytchev, Hibberd 2009; McDonald *et al.* 2009; Melia *et al.* 2009; Hola 2009, 2010; Shapira, Lyachin 2009; Kazlauskaitė, Bučiūnienė 2008; Babichenko, J. S., Babichenko, S. I. 2008; Hernaus *et al.* 2008; Reinhold *et al.* 2008; McCabe *et al.* 2008; Dejus 2011; Grybaitė, Tvaronavičienė 2008; Giretti *et al.* 2009; Stankuvienė *et al.* 2008; Idoro 2008; Zavadskas, Vaidogas 2008, 2009; Zavadskas *et al.* 2010; Enshassi *et al.* 2007). The problem of worker safety and the creation of healthy working conditions are very important issues because violations observed in this area bring not only moral

harm to workers, but often present a threat to their health and even lives (Alas, Edwards 2011; Liaudanskiene, Ustinovichius 2010; McCabe *et al.* 2008).

To reduce the rate of accidents and occupational diseases in the construction sector, for the last decades, a number of legislative acts have been adopted and implemented in the member-states of the European Union. The number of legislative documents regulating work safety is particularly large. These regulations refer to the management and control of work safety at an enterprise, rules on applying safety measures and industrial safety, the provision of workers with personal safety appliances and substances neutralizing harmful effects, investigation into the accidents at the workplace as well as occupational diseases, industrial breakdowns and their prevention. One of the main strategic tasks for developing the construction sector in Lithuania until 2012 is the creation of the system of construction codes and specifications regulating construction business that would meet the EU requirements and would be based on the experience of other countries.

The analysis of legal documents regulating construction work shows that provided information is precise and sufficient for creating a safe and sustainable working environment. However, the situation reflected by data on the rate of accidents and occupational diseases at construction enterprises is quite different. Statistical data show that the main causes are associated with the non-observance of construction codes and specifications and poor management of construction work. Moreover, workers often ignore requirements for using protective appli-

ances, are absent-minded and sometimes even drink alcohol at the workplace (Department of Statistics under the Authority of the Government of the Republic of Lithuania 2010). The number of fatal accidents in construction is three times as large as that in other EU countries. It should be taken into account that accidents in construction may be avoided not only by using personal protective measures and appliances or evaluating occupational risk and appropriate instructions of workers about the problems of safe and health protection, but also may be achieved by proper management of construction work and the creation of a safe working environment (Sawacha *et al.* 1999; Jorgensen *et al.* 2007). In many cases, the organization of work directly depends on the selection of appropriate solutions to structural, technological and safety problems. Therefore, one of the approaches aimed at improving the current situation in construction is the integration of structural, technological and safety solutions. In this case, the emphasis is placed on the analysis of a single object, consisting of the parts referring to three main areas, i.e. structural elements of a building, the technology of construction processes and their safety. The interrelationship between the criteria describing these issues and their integration affect each criterion describing these issues in a specific way. The performance of the system allows us to evaluate the effects produced by the interaction of each criterion between each other which helps with selecting appropriate structural, technological and safety solutions that in turn helps with preventing accidents and avoiding damages to human health.

According to Stewart (1986), it is usually not sufficient to determine the main cause of accidents. Other factors influencing the performance of the system in the considered period should be also identified (Withers 1988). Accidents usually occur due to the interaction between a great number of dangerous factors and risk factors that fail to be identified in most cases. As shown by Kletz (1994), non-dominant risk factors and the interrelationships between dangerous factors are not paid due attention. Inability to predict the performance of a system even under the influence of the main influencing factors is determined and show that the effect produced by each factor on system performance is not sufficiently known (Hadad *et al.* 2007).

To ensure system performance over the whole construction period, the authors of the present paper have developed a multi-stage model of structural, technological and safety solutions based on the analysis of literature on the discussed problem, statistical data, the experience of the EU member-states, strategic aims of Lithuania, a great amount of dangerous factors in construction and grave consequences of accidents in this sector. The created model is aimed at combining solutions worked out in the above-mentioned areas into a single research object. When using the tree diagram, the authors modelled and demonstrated a set of possible combinations of the available alternatives. The branches of the tree are linked because of the inherent relationships between structural, technological and works safety solutions.

The paper considers one of the most important tasks to be achieved in the construction sector, which is to ensure worker safety during the whole period of construction, i.e. to decrease the rate of accidents and occupational diseases or to completely avoid them. The problem is considered with respect to bricklayers, the profession of whose is one of the oldest and most popular. Work safety is an urgent problem for bricklayers exposed to danger at their workplaces that may be at a considerable height or be dangerous in any other way, thereby increasing the rate of occupational diseases and accidents. The aim of the authors is to offer a solution to the problem of decreasing the difference between the number of sustainable workplaces in the construction sector of Lithuania and other EU member-states by improving working conditions in the former.

## 2. Ensuring work safety and health protection of workers

The problems of labour and health protection should be implemented in the process of designing a building. Construction code “Building design” STR 1.05.06:2005 (2005) defines design stages, including the development of detailed design and contractor design. In general, one of the parts of detailed design is preparation for the construction and organization of construction work. The statements relating to these issues found in point 36 of code STR 1.05.06:2005 (2005) include:

- geological and hydro-geological conditions for the construction site;
- requirements for lowering underground water level;
- conditions for the preservation and use of trees, plants, black earth and spoil;
- buildings to be demolished and engineering systems to be removed;
- approximate amounts of various kinds of waste, in tons;
- conditions for suspending production or other economic activities during the reconstruction or overhaul of buildings;
- possibilities and conditions of temporary blocking road traffic;
- possibilities and conditions of getting an additional plot for storing building structures and materials, arranging building mechanisms and equipment and laying temporary roads and engineering systems;
- supply of power, water and other resources as well as the possibilities and conditions of removing and collecting sewage in the construction period;
- general requirements and conditions for safety, health protection and hygiene on the construction site;
- requirements for environment protection and protecting third party interests;
- a schedule for building construction and operations;
- a layout of the construction site, including particular solutions to the organization problems of construction work which must be implemented in

order to meet requirements for the particular parts of design.

Engineering design in construction should provide actual design solutions, determining technical devices and methods of work to be used and ensuring the safety and health protection of workers. These design solutions cannot be replaced with references to legal documents (or their parts) concerning the safety and health protection of workers, which only explains how to develop a particular design solution. To create sustainable working conditions, solutions concerning work safety should be defined in the engineering design of construction works. The following engineering solutions ensuring the safety of the performed operations should be described in the engineering (technological) design of construction works:

- safe sequence and duration of technological operations;
- the management of workplaces and provision of equipment and structures required for performing work (e.g. scaffolding, ladders, boarding, etc.);
- the organization of safe technological processes;
- the arrangement of erection equipment and marking dangerous zones of operation;
- the storage of prefabricated elements;
- calculating guy-ropes and devices;
- schemes for load suspension;
- methods for reinforcing structures to take over erection load;
- temporary fixing of structural elements in cases it is not provided in working drawings;
- drawings of work safety equipment and appliances or a list of standard drawings;
- work performance in cold and warm weather;
- the performance of dangerous and harmful works.

The engineering design of construction works should also provide for living conditions of workers, lighting on the construction site, workplaces and passages, telephone connection and an alarm system. Potential sources of danger should be listed and particular design solutions should be provided (e.g. strengthening slopes, the erection of scaffolding, etc.) in the section of work safety. The suggested design solutions should be scientifically grounded and described in detail when the calendar plan and layout of the construction site are developed. The choice of administration and utility rooms is substantiated and type designs are developed. The means of short-circuit and fire protection as well as environmental control are described. The calculations and descriptions of design solutions concerning work safety should be supplemented with diagrams and rough drawings. The funds required for implementing the means and methods of labour protection in a particular project should be mentioned.

The diagrams showing the sequence of technological processes and operations should present methods of work organization, the workplace of a worker and its provision with personal protection appliances. This helps with preventing from industrial injuries and occupational diseases. Technological diagrams based on the analysis of

data on industrial injuries are of a great practical value because they inform workers about possible accidents at the workplace, describe their causes and circumstances.

According to the specified sequence of technological operations, the lists of the main erection equipment, implements and materials required for the organization and performance of erection work should be presented. They should also provide data on the volume of erection work and labour expenditure.

The solutions, concerning erection work ensuring normal working conditions and work safety, should be described in the constituent parts of a technological scheme and therefore include:

- schemes for organizing erection work;
- the main statements about the sequence of various operations, the methods used and work organization;
- a schedule for the complex erection process;
- the tables of the main material and technical resources and devices;
- the estimate of labour expenditure.

The solutions presented in technological schemes provide the initial data and basis for developing a calendar plan in construction. At the same time, the problems of work safety are considered. The volumes of work and the time of performance are planned simultaneously with supplementary works and safe methods of work. The sequence of highly risky building operations, which could ensure the stiffness and stability of building elements as well as the duration and volume of works to be performed on the same vertical and some additional works are given in the calendar plan.

Measures for protecting from industrial injuries (caused by building machines, mechanisms, load suspension devices, etc.) and occupational diseases (caused by weather conditions, vibration, noise, etc.), not connected with losses of power and material resources, should be included in the plan of work safety and health protection as routine affairs for the construction period. All works, aimed at creating appropriate working conditions and ensuring work safety, are included in the nomenclature of production processes. Only when engineering solutions to the safe performance of work are made, the time of performing some particular works may be reduced in the calendar plan.

The layout of the construction site considers the following problems associated with improvement in working conditions and fire and environment protection:

- putting up a fence around the construction site;
- temporary utility and service rooms for construction workers and servicing people of building equipment;
- rational spacing of storehouses for materials and storage areas for structures;
- safe methods of loading materials, devices and structures (based on work mechanization and automation);
- the layout of temporary service lines (e.g. power networks, water supply lines and sewerage nets);

- the characteristics of safe working conditions;
- spacing fire hydrants or water tanks and fire extinguishing devices;
- the storage of poisonous, combustible and explosive materials;
- the location of warning boards and signs;
- lighting of the construction site: local or general lighting;
- the protection of landscape, plants and water;
- waste disposal sites.

While developing design solutions, it is necessary to determine all dangerous and harmful effects produced by construction works and working conditions indicating the affected zones and risks of performing dangerous operations and using dangerous equipment.

Detailed (construction management) design should indicate dangerous zones around hoisting machines while other dangerous areas should be shown in engineering (construction technology) design.

Temporary utility and relaxation premises and roads should be located beyond dangerous zones.

When conditions for construction influencing safety and health protection have changed, engineering design (of construction work execution) should be modified and/or corrected.

The design of construction work technology (execution) should define:

- the sequence of operations for structure erection and equipment installation;
- a reduction in the volume of works performed under hazardous and unhealthy conditions;
- safe arrangement of building machines and equipment;
- the equipment of workplaces taking organizational safety measures and using technical appliances;
- work implements, collective and individual protective appliances;
- lighting on the construction site, workplaces and roads, signs of work safety and health protection, alarm and communication systems;
- the equipment of temporary utility premises.

To prevent workers from falling from height, engineering (technological) construction design should include:

- design solutions allowing for reducing the volume of high-altitude works;
- the erection of permanent enclosing structures (e.g. walls, staircases, balconies, etc.) as a top priority task.

Engineering design should also define:

- the location and types of temporary enclosing structures;
- places of fixing safety ropes and belts;
- the main and supplementary equipment for high-altitude works;
- the techniques used to allow workers to get to workplaces;
- remote control devices for load unhooking, if required.

To avoid falling structures, building products and materials from height, engineering (technological) design should provide for:

- containers and packing for transporting solid and granular materials as well as concrete and mortar;
- hoisting devices (slings, spreaders and beam clamps);
- suspension methods allowing for transporting the elements to be stored or assembled to the required place;
- devices (pyramids, holders) ensuring the stability of the stored structural elements;
- methods and areas for storing products, materials and equipment;
- methods for temporary and permanent fastening of assembled and disassembled structures;
- methods for temporary fastening of structural elements when dismantling buildings and building constructions;
- methods for removing waste materials and debris;
- the arrangement and structure of protective floors or roofs.

When building machines and mechanisms are used, engineering (technological) design should include:

- the types of building machines and mechanisms, their location and mode of operation depending on the conditions of construction and construction technology used;
- methods and techniques for eliminating and/or reducing the harmful effect of dangerous agents on the operator or other people working nearby;
- methods for restricting the working area of a building machine to avoid the places of people gathering and surrounding this area with a fence;
- specific conditions for setting up building machines within landslide areas such as on the fill-up soil, on the slope, etc.

When operations are performed in depressions (hollows) or trenches, design should determine:

- a safe slope of the hollow or methods and techniques for consolidating the slopes of the hollows;
- the ways of entering hollows or trenches and going out of them;
- methods of removing water, if required.

In order to protect workers from electric shock, design should provide for:

- the installation of temporary electrical devices, voltage, temporary electric cable routing and lighting as well as the ways of enclosing parts drawing a current and the arrangement of power supply and distribution networks and devices;
- methods for earthing (grounding) the metal parts of electric devices;
- additional protective measures to be taken in performing operations in dangerous and very dangerous zones inside and outside the buildings;
- safety methods for operation in the protective areas of power lines and near working electric devices.



To protect the workers from the harmful effects of noise, vibration and poisonous substances in the air of the working area, it is necessary:

- to determine workplaces where harmful effects may be caused by technology used or the conditions of construction work;
- to provide for measures protecting workers from harmful effects associated with construction;
- if required, to provide for places and methods of storing harmful or dangerous substances.

The plan of equipping workplaces should propose the following organizational measures ensuring the protection of workers and their health:

- works requiring special admittance or permit for their performance;
- joint measures to be taken by the contractor and customer to ensure the safety and health protection of workers working on the territory of the operating enterprise;
- the performance (sequence) of construction works in case there are several contractors on the same construction site taking into account the plan of measures ensuring worker safety and health protection on the construction site.

Requirements for ensuring the safety and health protection of workers at the working place are so numerous that they are not often reflected in technological construction design, which leads to accidents and occupational diseases. To avoid or reduce them, solutions to safety problems should be included into technological construction design at the initial stage of its development. Construction operations should be managed so that the safety of workers is ensured over the whole construction period, thereby helping to avoid accidents and occupational diseases or at least to reduce their number. The applied construction technology should ensure the quality and safety of work and meet the requirements presented in “Building Design” STR 1.05.06:2005 (2005).

To meet requirements for worker safety and health protection, to control the situation and to avoid accidents in construction, effective measures ensuring worker safety at the workplace should be taken. One of the methods that may positively affect the development and maintenance of the sustainable workplace over the whole construction period is a joint analysis of structural, technological and safety solutions (Fig. 1). A technological solution is made when a detailed as well as feasibility analysis of building processes and their implementation are made. Such technological solutions ensure structural strength, durability and workplace safety.

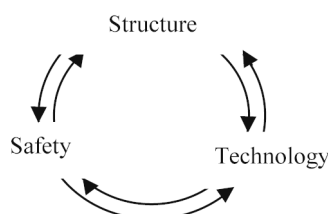


Fig. 1. The constituent parts of the construction project

To avoid any misunderstanding, the terms *structure*, *technology* and *safety* should be defined, i.e. their exact meanings in the context of the sustainable workplace should be given:

- *Structure* means the structural elements of a building aimed at carrying loads (of structures, equipment, snow, wind, people, ground, etc.) and ensuring the mechanical strength and durability of the building.
- *Technology* denotes construction works ensuring the execution of the whole construction process.
- *Safety* denotes all protective techniques and appliances aimed at ensuring the workability and protection of the health and lives of the workers at the workplace. These measures are planned and implemented at all stages of enterprise operation to protect workers from occupational risk or at least to reduce it.

### 3. The tree of structural, technological and safety solutions

To develop the tree of structural, technological and safety solutions, a comprehensive feasibility study on their operation and practical application is required. In the considered case, trees are suitable for a graphical presentation of a relatively complicated process of decision making when its consequences, costs and risks are unknown. The main advantage of this approach is that it allows for comparing two or more working processes under uncertainty conditions (concerning the results to be obtained). The main aim of using the tree is to graphically show all interrelated decisions and situations, so that all decision alternatives and the main criteria could be clearly seen and allow the users to choose particular methods of analysis.

In practice, to make a decision, a great number of alternatives should be considered. Any of them should be defined and the results of its application should be studied. It is usually hardly possible to determine all factors influencing the result of decision making. Sometimes, it is possible to find some probabilities of the occurrence of these influencing factors or at least the distribution of a random value relating to these factors as to the whole integral (Popov *et al.* 2010). However, in many cases, the theory of probability cannot be applied to decision making. Then, a set of available alternatives should be considered, the data referring to them should be stored and the consequences of any decision should be calculated (if possible). Finally, the methods of choosing one of the available alternatives should be suggested or the possibility of a logical analysis of a set of possible decisions should be provided. All decisions related to each other in any way are presented as branches allowing us to determine the possible results of decision making. Tree modelling is a valuable tool that may be used for solving various problems of decision making.

In literature, the use of the decision tree under determined conditions, e.g. the analysis of decisions relating to construction processes (Šarka *et al.* 2008; Šostak, Vakinienė 2010; Polaka, Borisov 2010; Zavadskas and

Vaidogas 2009; Zavadskas *et al.* 2010; Hola 2010 ; Déjus 2011), large organisations (Cabantous *et al.* 2010) or uncertainty conditions (Sutiene *et al.* 2010; Moussa *et al.* 2006) is described.

The tree diagram is also used when events do not take place according to the available strategies, or if they do, probabilities are different. This diagram may be also useful when there is a possibility of postponing decision making for some time, carrying out an experiment or gathering some additional information.

The tree diagram allows us to classify the available data into groups and to predict dependent variables based on known independent variables. This is a useful tool for exploratory and confirmatory discriminant analysis and may be used for:

- identifying data based on their belonging to a particular qualification group;
- attributing data to a particular (e.g. small-, medium-or high-risk) group;
- predicting future events using the developed model;
- compressing the available data, reserving only independent variables statistically significant for dependent variable prediction (out of a large group of independent variables);
- identifying the interaction between particular groups.

When the tree is constructed, it helps with simplifying the analysis of the problem because, in this case, the results of any decision made are evident. Moreover, you may change some data and assess the significance of additional information. All calculations made to evaluate decisions are rather simple. For these reasons, it is advisable to construct the trees and use reliable results yielded by this method.

Statistical data and a plan of preventive measures play an important part in developing the tree of structural, technological and safety solutions associated with the avoidance of accidents and occupational diseases. The analysis of the accidents at construction enterprises shows that about 60 per cent of all accidents take place because of poor work organisation on the construction site (Department of Statistics under the Authority of Lithuanian

Government 2010). Falling of workers from height, though not making the most common type of accidents, leads to the most serious consequences and is most expensive. The analysis of accidents at the workplace according to the type of work performed shows that the accidents most often occur when the earth moving and erection of the exterior walls are performed. This happens because naturally loose soil is not consolidated, which leads to earth crumble. In the case of erecting exterior walls, the wrong type of scaffolding is often used. Besides, work is often performed hastily, not taking into account the specificity of the used technology etc.

The principle underlying the construction of the tree for solving structural, technological and safety problems may be applied to all construction processes. In the considered case, attention is paid to the erection of exterior walls. Various wall structures are available to satisfy customers' requirements and different architectural solutions (Table 1).

Taking into account the type and complexity of structure and a construction site, construction technology is chosen and solutions to safety problems are evaluated (Fig. 2).

Though various solutions to external walls are possible, masonry construction takes the second place after prefabricated construction. This is mainly the construction of masonry buildings. In case they are built of other materials, brickwork is still used in some parts of a building, e.g. partitions, chimneys, fireplaces, setting the interior and exterior of a building with finishing materials or artificial and natural stone, etc. Bricklayers should be able to erect reinforced concrete structures, which is done simultaneously with masonry work. This includes the erection of lintels, staircases, flights, balconies, parapets, floor slabs and other elements. Bricklayers should be able to brick walls of various structures, use various materials and know the technology of work. A bricklayer is not only the oldest, but, probably, the most popular profession in construction. For these reasons, the authors of the present paper analyse potential dangers at the bricklayer's workplace and evaluate possible structural, technological and safety solutions.

**Table 1.** Structural solutions to exterior walls

Wall structures	Erection of prefabricated structures	Metal structures	Sandwich metal slabs
			Metal sheets
		Glass structures	Frameless tempered glass window panes
		Reinforced concrete structures	Three-layer reinforced concrete slabs
		Facing slabs structures	Ceramic veneers
		Timber framework structures	Timber products
	Composite structures		Aluminium-timber-glass products
			Timber-glass products
			Aluminium-glass products
	Erection of cast-in-place	Cast-in-place reinforced concrete structures	Multilayer concrete slabs
			Cast-in-place reinforced concrete
	Erection of masonry structures	Masonry structures	Single-layer masonry
			Two-layer masonry
Three-layer masonry			
Reinforced concrete masonry structures		Masonry and reinforced concrete products	

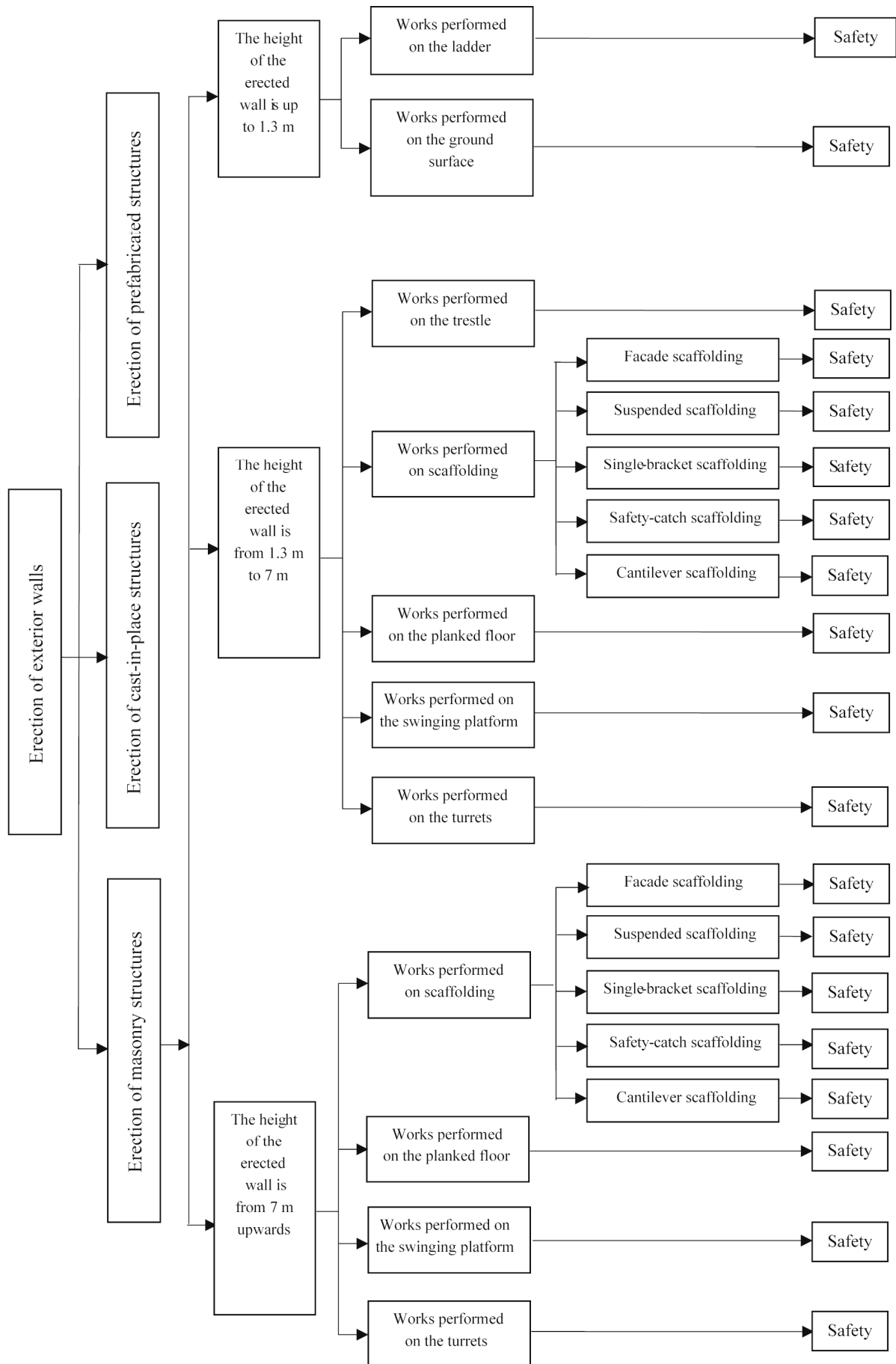


Fig. 2. A tree diagram of erecting exterior walls

The bricklayer's workplace may be uncomfortable, unsafe, exposed to bad weather, etc. The expected risks/harmful effects on the construction site are as follows:

- an uncomfortable working position because of an improper level of working surface, need for repetitive movements and non-ergonomic arrangement for workplaces and materials;
- moving over uneven, slippery surface having sharp objects and other obstacles present a threat to the worker of hurting or falling from height;
- carrying equipment and materials presents the risk of falling from height, hurting (hands and back in particular), overloading joints, etc.;
- the risk of falling from height when walking on scaffolds, partitions with spans or along the edge of the structure as well as when scaffolds are assembled or disassembled or when walking to the workplace located very high, etc.;
- cleaning something under high pressure produces dust and noise, and therefore may cause the inflammation of eyes as well as present the risk of hurting the worker if the hose breaks;
- the risk of falling stored products or materials that may compress and force the worker to fall down;
- working in semi-darkness or under artificial lighting presents the risk of eye-sight weakening or hurting the worker;
- disassembling structures made of old structural elements presents the threat of falling down, produces dust and spreads various bacteria, parasites and rodents that may cause different diseases;
- the movement of workers in the areas of car traffic and in dangerous zones where various building machines and cranes are used may lead to accidents in which workers may be hurt;
- work on load-bearing structures presents the risk of falling from height;
- disassembling or demolishing buildings or temporary structures (e.g. scaffolds, supports, etc.) presents the risk of compressing or crushing workers and falling from height;
- work near sharp objects, reinforcing bars, metal structural elements, etc., presents the risk of pricking or otherwise hurting workers;
- work near power lines, wiring, etc. poses the risk to workers of getting an electric shock;
- work in cold and heated premises, cold and hot weather as well as under solar ultraviolet rays may produce a harmful thermal effect on workers;
- contact with concrete, cement, mortar, paint, glue, lacquers, diluents and other chemical materials presents the risk of hurting skin and poisoning workers;
- cutting, drilling or grinding bricks or other building materials produce dust, vibration and cause burns and other injuries to workers;
- the use of broken hoisting devices (winches, pulleys, etc.) and their accessories presents the risk of hurting workers when load falls;
- the use of portable cutting, drilling, perforating and erecting (electric, pneumatic, thermal, etc.) tools presents the risk of cutting themselves or suffering from noise, vibration, electric power, radiation, etc.;
- the use of various sharp tools present a threat for workers to cut themselves;
- the use of hoisting and lowering devices (lifting platforms, hoists, etc.) may cause a danger to workers of hurting themselves or falling from height;
- the use of high-altitude devices (platforms, ladders, etc.) poses the risk of falling from height;
- the risk of being hurt by things falling from height;
- mental overloads, stresses caused by the sense of responsibility, work pace and other risk factors.

In fact, these risks/harmful effects are found actually on any construction site, irrespectively of time and place to perform construction work. To reduce the risk of short-term unexpected threat, the following preventive measures of organisational nature should be provided: clearly defined work for a manager or foreman responsibility to solve urgent problems, instruction and information about the person(s) to whom they should apply if some problems arise, the interaction between construction work coordinator, particular employers or managers and workers, timely provision of process charts (flow sheets) or the adaptation of standard process charts to the current situation as well as the provision of work descriptions and preventive measures for developing the plan of labour protection ensuring its quick correction according to recommendations, if required, control over the work of responsible persons, etc. To ensure a reduction in real threats to workers on the construction site, it is necessary to predict all dangerous situations and risks and to make sure that reducing one risk factor would not increase another. The cases should be considered, when under changing working conditions and the environment as well as taking into account available protective measures, permanent monitoring of this system should be implemented to check if the available protective appliances are sufficient or some additional or completely new ones should be introduced. All the participants of the construction process should work according to their responsibilities: to assess risks to workers' safety and health and to ensure that preventive measures should be incorporated into the integral whole of organizational and architectural works during building construction and maintenance.

Based on the above-mentioned relationships between the constituent parts of the construction project embracing structural, technological and safety requirements, the authors offer a multistage model for solving the problems of construction work safety, as presented in the tree diagram (Fig. 3).



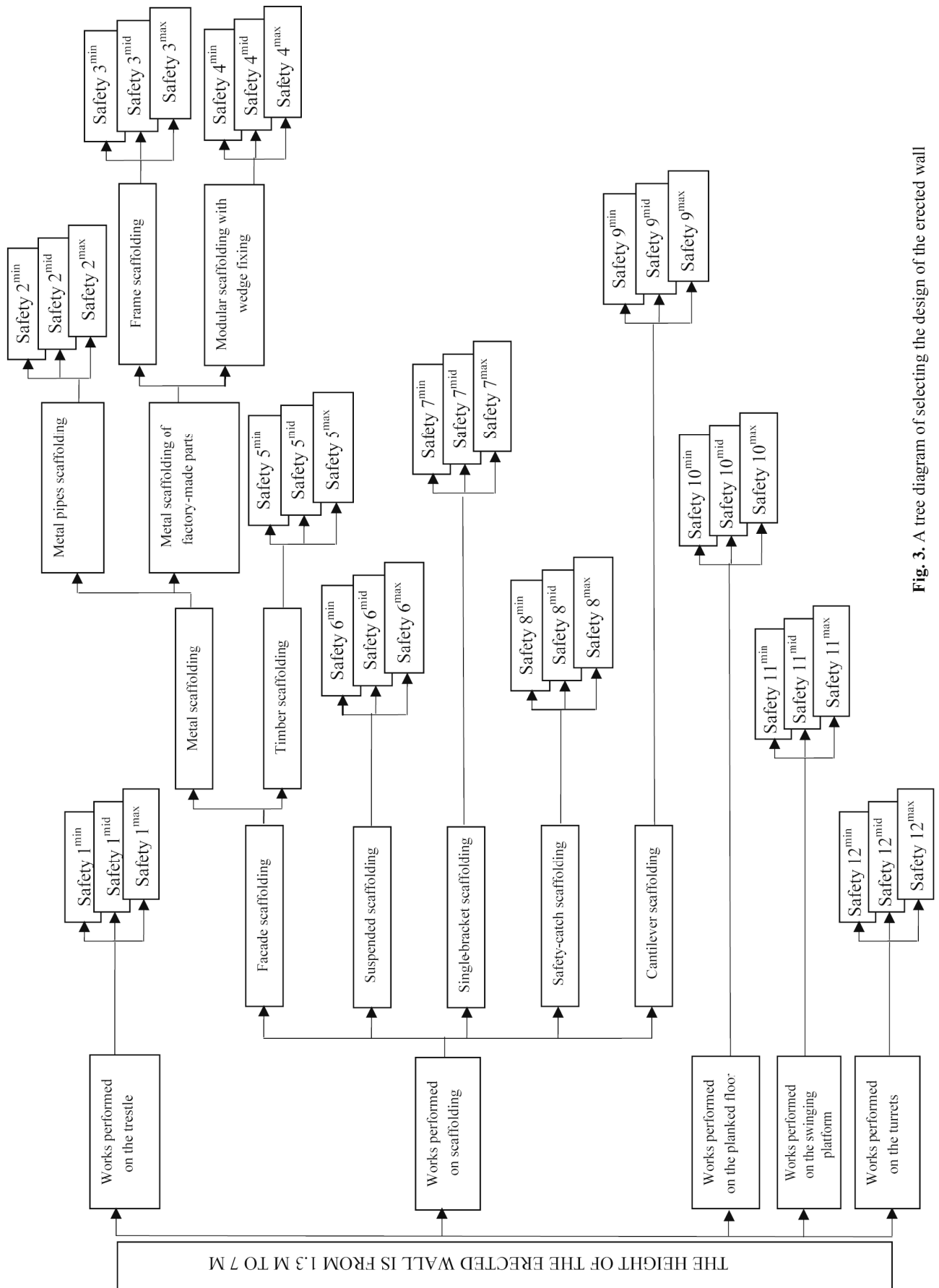


Fig. 3. A tree diagram of selecting the design of the erected wall

#### 4. Formalization of the suggested model using the tree diagram

The developed new multistage model reflects the structure of the analysis of combinations with structural, technological and safety alternative decisions. This structure is presented as a tree diagram and is described by using the notation as follows:

1. A set of stages of decision analysis  $K = \{k\}$  ( $k = 1, 2, 3$ ),  $k$  is the stage number;
2. The number of the nodes of the tree at each stage is  $m_k$  ( $k = 1, 2, 3$ ):
  - a) the number of alternatives to the stage of structural decisions ( $k = 1$ ) is  $m_1$ ;
  - b) the number of alternatives to the stage of technological decisions ( $k = 2$ ) is  $m_2$ ;

$$m_2 = \sum_{i=1}^{m_1} t_i, \quad (1)$$

where  $t_i$  is the number of possible alternatives to technological decisions on the  $i$ -th structure.

- c) the number of alternatives to safety decisions at stage ( $k = 3$ ) is  $m_3$ :

$$m_3 = \sum_{i=1}^{m_2} s_i, \quad (2)$$

where  $s_i$  is the number of possible alternatives to safety decisions on the  $i$ -th technology.

3. The number of the modelled tree branches connecting the root node to the finite node (called a leaf) is  $z$ , ( $z = m_3$ ).

Based on the above-mentioned relationship between the constituent parts of the construction project (Fig. 1), the trees (Figs 2 and 3) and the defined tree notation, we suggest the development of the multistage (three-stage) tree. This model of decision analysis represents all possible alternatives to designing the erection of external building wall as well as interrelating structural, technological and safety solutions (Fig. 4).

The notation in the tree diagram given below is as follows:

- *Const.i*, ( $i = 1, 2, \dots, m_1$ ) is the number of the  $i$ -th structure (e.g. *Const.1* is the number of the 1<sup>st</sup> structure);
- *Techn.i/j*, ( $i = 1, 2, \dots, m_1$ ;  $j = 1, 2, \dots, t_i$ ) is the number of the  $j$ -th technology of the  $i$ -th structure (e.g. *Techn.1/1* is the number of the 1<sup>st</sup> technology out of all possible technologies of the 1<sup>st</sup> structure);
- *Safety.i/j\_a*, ( $i = 1, 2, \dots, m_1$ ;  $j = 1, 2, \dots, t_i$ ),  $a = \{\min, \text{mid}, \max\}$  is the number of the  $a$ -th type safety solution of the  $j$ -th technology of the  $i$ -th structure (e.g. *Safety.1/1\_min* denotes minimum requirements for the 1<sup>st</sup> technology of the 1<sup>st</sup> structure).

A branch of the tree presents one of possible alternative combinations shown by the following examples given below.

Based on the data displayed in diagrams 2 and 3, the 1<sup>st</sup> and 5<sup>th</sup> branches of the tree (Fig. 4) are described as follows:

*Const.1 -> Techn.1/1 -> Safety.1/1\_min* denotes the construction project of the external wall, including masonry structures for erecting 1.3–7 m high walls using technology “Works performed on the trestle” and choosing minimal work safety requirements;

*Const.1 -> Techn.1/2 -> Safety.12/\_mid* denotes the construction project of the external wall, including masonry structures for erecting 1.3–7 m high walls using technology „Works performed on facade metal pipe scaffolding“ and choosing intermediate work safety requirements.

#### 5. Conclusions

1. Accidents at the workplace and occupational diseases closely associated with human sufferings and large expenses have been a matter of great concern at the national and international level for a long time now. The creation of the sustainable workplace is based not only on knowledge of the legislative basis and satisfaction of particular requirements, but also on an appropriate choice of technological processes and safety solutions.

2. To create and maintain a sustainable workplace during the construction process, solutions to structural, technological and safety problems should be combined into the integral whole. In this case, the emphasis is placed on a single object the constituent parts of which refer to three main areas, i.e. structural elements of a building, the technology of construction processes and solutions to their safety.

3. Taking into account the relationship between achieved solutions and having analysed the state of worker health protection in the construction sector of Lithuania and other EU member-states, the authors created a new complex decision model and presented it as a tree diagram. The relationships between influencing factors (criteria) and their integration have a specific effect on each particular factor. The performance of the system allows for evaluating the effects of the interaction of any criteria with others. This helps with ensuring an appropriate choice of structural, technological and safety solutions, which in turn helps with saving human lives thus avoiding harmful effects on human health.

4. The present paper analyzes the bricklayer’s workplace. The conducted analysis has revealed a great number of risk factors and potential threats to the workers at the workplace. The assessment of the bricklayer’s workplace and the possibilities of creating a tree diagram allowed the authors to develop a new multistage decision model presenting the structure of the analysis of alternative decision combinations referring to structural, technological and labour protection aspects of the construction process. The authors are planning to use the developed decision model for analyzing solutions to similar problems. They also hope for suggesting a decision method allowing for selecting the most optimal variant out of a set of alternative combinations.

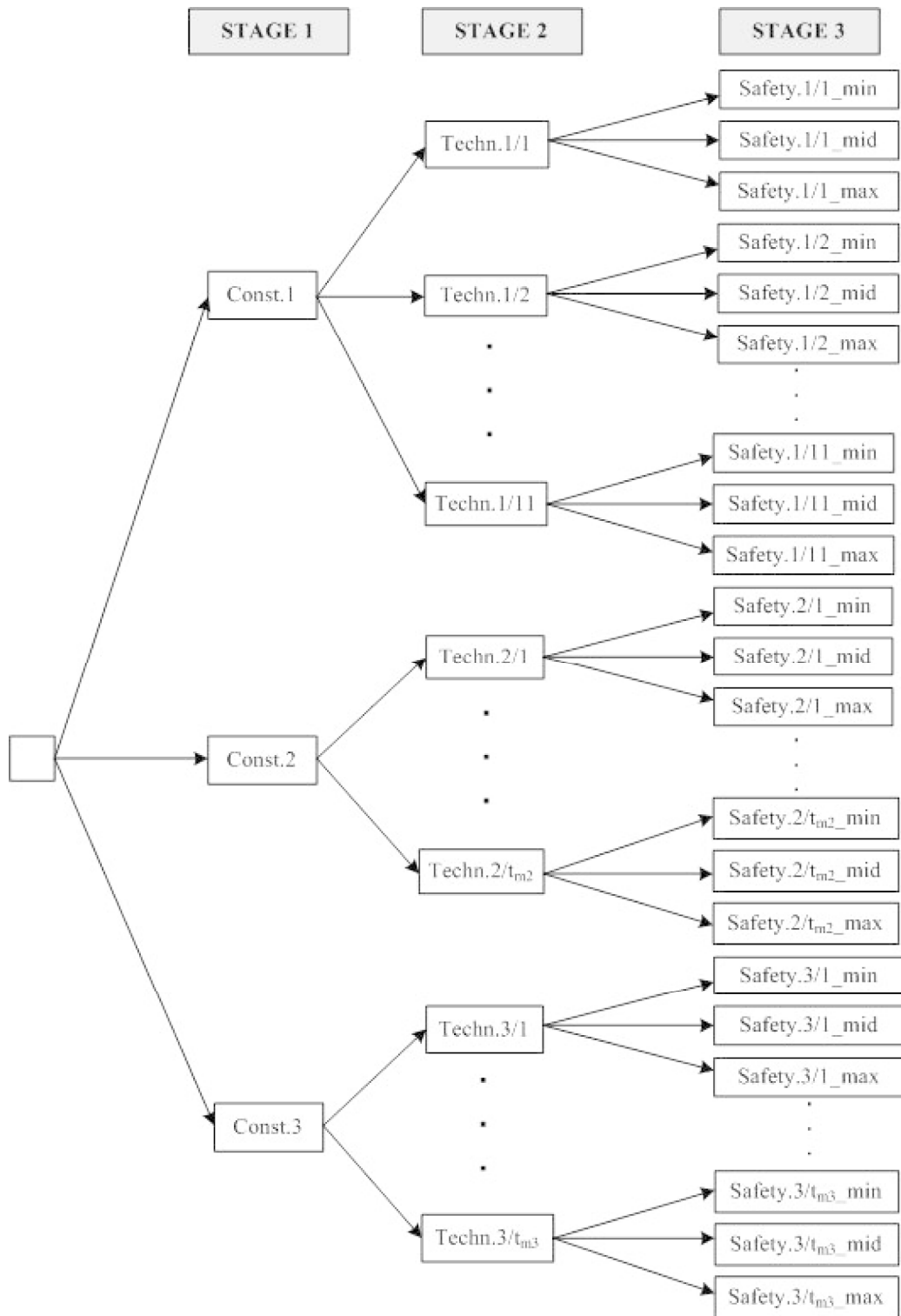


Fig. 4. A three-stage tree diagram of a construction project

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## KONSTRUKCINIŲ, TECHNOLOGINIŲ IR SAUGOS PROBLEMŲ SPRENDIMO MODELIS

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Santrauka

Šiame darbe autoriai sukūrė konstrukcinių, technologinių ir saugos sprendimų modelį, taikydami sprendimų analizės ir vizualizavimo įrankį – sprendimų medį. Pagrindinė šio modelio paskirtis – sujungti trijų sričių sprendimus į vieną bendrą nagrinėjamą variantą. Sukurtas daugiapakopis sprendimo modelis, vaizduojantis galimų alternatyvių derinių aibę. Sprendimų medžio šakos tarpusavyje sujungiamos remiantis esamu konstrukcijų, technologijų ir darbų saugos neatsiejamu ryšiu. Veiksnių sąveikos ir susijungimas turi unikalią įtaką kiekvienam veiksmui. Sistemos veikimas leidžia įvertinti kiekvieno rodiklio sąveikos poveikį, o tai padeda užtikrinti tinkamą konstrukcinių, technologinių ir saugos sprendimų pasirinkimą, sudaro prielaidą įgyvendinti statybos projektus išsaugant žmogaus gyvybę ir užkertant kelią galimiems sveikatos sutrikdymams.

**Reikšminiai žodžiai:** darbuotojų sauga ir sveikata, nelaimingas atsitikimas, profesinis susirgimas, statybų sektorius, statybos procesas, darni darbo vieta, medžio diagrama, sprendimų analizė.

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