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# DESIGNING A MOBILE FIELD HOSPITAL OF A MODULAR TYPE

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**Abstract.** The article analyzes the main designs of mobile hospitals and classifies them according to their functional purpose. Basic three-dimensional models have been developed and proposed, with their maintenance features described. Typical dimensions of mobile field hospital structures have been determined. The results of modeling in the Autodesk CFD environment are presented.

**Keywords:** CAD, field hospital, Autodesk Inventor, Autodesk CFD, 3D modeling, military medicine.

## Introduction

Despite the difficult historical path of Ukraine's formation, new challenges arise today, driven by economic, social, and, most importantly, military-political factors. These circumstances necessitate adaptation to the realities of technological progress, as well as the implementation and development of advanced innovations across various industrial sectors. Currently, there is a rapid increase in the production and use of paramilitary and military-purpose goods. Notably, significant progress is being made in solving tasks such as modeling robotic platforms [1], developing efficient navigation systems, and creating UAVs with both long and short-range capabilities, among others. However, the focus is not solely on developing new intelligent tools for neutralizing adversaries. Models, methods, and tools for protecting soldiers on the battlefield have also seen further advancements, as the lives of individuals remain a top priority. Therefore, research dedicated to modeling and deploying next-generation modern field hospitals is particularly relevant.

## Problem Statement

It is evident that the issue of modeling research cannot be considered outside the military context. This is crucial for understanding the potential practical benefits and effectiveness of implementing such concepts. Mobile medevac units with varying levels of protection are primarily designed to provide initial aid and stabilize wounded personnel. Subsequently, the injured are transported to a hospital. However, frequent violations of the Geneva Conventions and other rules of warfare by the Russian side—such as attacks on hospitals and clinics—often make such transportation impossible. This is exacerbated by significant distances to the front lines, mined roads, and enemy fire control.

There are a number of solutions that can partially, or even substantially, address this gap. These include modular field hospital systems. Currently, Ukraine is receiving such technical solutions from Western partners. Their main advantage lies in mobility: when specific threats arise or the operational situation changes, these hospitals can be relatively quickly relocated. Such flexibility in conflict zones helps save the lives of both medical personnel and patients [2].

Additionally, this approach optimizes resource use by allowing the combination of different sections to meet specific needs, increasing adaptability to operational conditions and assigned tasks.

In today's world, acute geopolitical issues often escalate tensions between countries and deepen global polarization. For this reason, finding solutions to reduce the cost of mass-producing such field hospitals has become a priority. This involves using construction materials and technologies applied in private housing, such as 3D printing with polymers, specialized concrete mixtures, and composites. This layer-by-layer process is often referred to as additive manufacturing [3]. Furthermore, modern communication systems, control devices, and smart home technologies [4] are actively being integrated into these systems [5].

Another significant advantage of such developments is the improvement of logistical hubs, creating a network of medical aid centers. This enables more efficient resource distribution, reduces the time needed to deliver medical supplies, and saves fuel, thereby enhancing logistics. In addition, it simplifies inventory management of hospital equipment and ensures readiness for deployment to high-risk areas when required.

## Main Material Presentation

Based on the analysis of common technical solutions for mobile hospitals, there is significant diversity in military medical facilities among different armies worldwide. This is primarily due to organizational approaches to the purpose and role of field hospitals. For instance, the structure of the U.S. Armed Forces includes an Evacuation Hospital, Mobile Army Surgical Hospital (MASH), Combat Support Hospital (CSH), Field Hospital, and General Hospital. These are all facilities capable of providing medical services in conditions of armed conflicts or military operations [6].

Field hospital designs can be classified into primary types based on their functional purpose:

1) Mobile Field Hospitals

This type is designed for rapid deployment and convenient transportation. They consist of modular units that can be quickly assembled and disassembled, making them ideal for emergency response situations. Mobile hospitals are indispensable for delivering medical aid in remote areas with inadequate or damaged infrastructure.

2) Tent-Based Field Hospitals

One of the most common types, these use tents with enhanced durability and waterproofing to create temporary medical shelters. They are widely used during military operations and in the aftermath of natural disasters when existing buildings are damaged or unsuitable for medical needs. This design allows medical care to be provided under resource-limited conditions.

3) Container-Based Field Hospitals

Constructed using shipping containers, these hospitals offer exceptional durability and mobility. They provide greater stability and longevity compared to tents, enabling the development of a more advanced medical infrastructure.

4) Modular Field Hospitals

These hospitals consist of prefabricated components assembled directly on-site. They are highly flexible and can be adapted to various medical tasks, from providing primary care to supporting complex surgical or intensive care units.

5) Hybrid Field Hospitals

Hybrid hospitals combine the best features of mobile, tent-based, container-based, and modular types. They can quickly reconfigure and expand based on needs, making them effective in diverse conditions.

To select the most suitable type of field hospital, the Analytic Hierarchy Process (AHP) was applied [7,8]. This method involves decomposing the problem into increasingly simple components and processing the judgments of decision-makers. First, the selection criteria were identified, comprising six factors: durability, deployment speed, flexibility, scalability, versatility, and resource demand. A criteria matrix was constructed. Notably, all elements along the main diagonal of the matrix are equal to 1, as they represent comparisons of identical concepts. However, other cells do not follow this pattern, as they compare different criteria in terms of their content and importance. Evaluation is conducted using a tenpoint scale for each pair of criteria, with higher scores indicating a stronger preference for one criterion over another. To derive the eigenvector components, the product of all row elements is calculated and then raised to the power of 1/n1/n, where nn is the number of criteria. The sum of these values is needed to normalize the priority vector by dividing each component score by this total. Further calculations are detailed in tables.

*Table 1*

***Criteria matrix***

| Критерії підбору | Durability | Deployment speed | Flexibility | Scalability | Versatility | Resource demand | Eigenvector component estimates | Normalized priority vector estimates |
|---|---|---|---|---|---|---|---|---|
| Durability | 1 | 2 | 4 | 6 | 8 | 9 | 3,888322594 | 0,428744 |
| Deployment speed | 0,5 | 1 | 2 | 4 | 6 | 9 | 2,449489743 | 0,270092 |
| Flexibility | 0,25 | 0,5 | 1 | 3 | 2 | 6 | 1,284898293 | 0,141679 |
| Scalability | 0,166667 | 0,25 | 0,333333 | 1 | 1 | 5 | 0,641120383 | 0,070693 |
| Versatility | 0,125 | 0,166667 | 0,5 | 1 | 1 | 4 | 0,588795922 | 0,064923 |
| Resource demand | 0,111111 | 0,111111 | 0,166667 | 0,2 | 0,25 | 1 | 0,216465633 | 0,023868 |
| Sum | | | | | | | 9,069092568 | |

*Table 2*

***Checking the correctness***

| Sum by columns | 2,152778 | 4,027778 | 8 | 15,2 | 18,25 | 34 | Sum $L_{max}$ |
|---|---|---|---|---|---|---|---|
| Product of the sum by columns and the normalized priority vector estimate | 0,922991 | 1,087871 | 1,133431 | 1,074532 | 1,184851 | 0,811529 | 6,2152048 |

The consistency index is calculated as (6.215204847−6)/(6−1)=0.043040969, and the consistency ratio as (0.043040969/1.24)×100=3.471045921 (%). Note that the obtained value is less than 10%, indicating that the criteria have been evaluated objectively. Here, 1.24 is a fixed value corresponding to the random consistency index for a sixth-order matrix.

*Table 3*

***Matrix of global priorities***

| Alternatives | Criteria | | | | | | Global priorities |
|---|---|---|---|---|---|---|---|
| | Durability | Deployment speed | Flexibility | Scalability | Versatility | Resource demand | |
| | Numerical value of the priority vector | | | | | | |
| | 0,429 | 0,270 | 0,142 | 0,071 | 0,065 | 0,024 | |
| Container-based | 0,404 | 0,247 | 0,135 | 0,171 | 0,123 | 0,184 | 0,283500367 |
| Modular | 0,246 | 0,356 | 0,225 | 0,543 | 0,213 | 0,109 | 0,288147846 |
| Mobile | 0,246 | 0,299 | 0,076 | 0,100 | 0,067 | 0,090 | 0,210393442 |
| Hybrid | 0,079 | 0,068 | 0,539 | 0,151 | 0,569 | 0,033 | 0,177037876 |
| Tent-based | 0,026 | 0,030 | 0,026 | 0,035 | 0,028 | 0,584 | 0,040920471 |

Next, a similar analysis is conducted for all the given criteria, using the alternatives as column and row labels. Since there are five types of hospitals rather than six criteria, the random consistency index is taken as 1.12.

Subsequently, the global priority vector must be calculated based on the provided data. The normalized priority values for each criterion are entered into the corresponding column. Each criterion's weight is multiplied by the priority score of each alternative for that criterion, and the values are summed for each row.

The modular type of field hospitals received the highest weight score, allowing us to conclude that, despite some shortcomings, it is the most optimal option among those presented. However, the container type also performed well, only slightly trailing behind in ranking. Therefore, we will take a closer look at the main advantages and disadvantages of each type.

*Table 4*

***Advantages and disadvantages of each type of field hospital***

| Type | Advantage | Disadvantages |
|---|---|---|
| Mobile | Can relocate to a designated area within a relatively short period of time | Limited equipment, which prevents the conduct of prolonged military operations |
| Tent-based | Easy to set up and maintain | Vulnerable to weather conditions |
| Container-based | A cost-effective option for mass production, simple for scalability | Requires additional resources for deployment |
| Modular | Can be adapted to specific tasks, such as operating rooms or diagnostic centers | Requires significant funds for development and operation |
| Hybrid | Provides a wide range of medical services, combining the advantages of different types of hospitals | Creates additional strain on logistics and organizational coordination |

***Determination of basic requirements.*** Based on the analysis of works [9-12], the main requirements have been identified:

1) Mobility: All modules must be transportable, meaning they should be easily moved by various types of transport (trucks, airplanes, helicopters).

2) Autonomy: The presence of autonomous life support systems, such as power generators, water supply systems, heating, and cooling systems.

3) Capacity: The ability to simultaneously accommodate and treat at least 50-100 wounded or sick individuals, depending on the scale of the task.

4) Scalability: The system must support the reduction in the number of modules according to the situation.

5) Protection: Modules should be equipped with armor plates and evacuation means.

Indeed, a high-quality final product is hard to imagine without the combination of all these elements. Only by fully considering these requirements can the effectiveness of using a mobile hospital be enhanced.

***Schematic materials.*** We will use the UML language to define and visualize the proposed approach for solving the field hospital modeling task. A context diagram has been developed (Fig. 1), illustrating the flow of global processes in the operation of a field hospital. It consists of four inputs, four control elements, four mechanisms, and one functional block. Thus, all four inputs are processed in the functional block "Operation of a Mobile Field Hospital" using mechanisms and in compliance with control requirements, resulting in three system outputs. Let’s take a closer look at each component of the context diagram.

The left side corresponds to the system’s inputs – objects used by the system for further procedural processing and transformation. It is allowed that a process may not have any input arrows. In my implementation, the following values of this type and purpose are present: "Fuel and lubricants", "Patients", "Provisions", "Sanitary supplies".

The top side corresponds to the control inputs: information, procedures, rules, strategies, and standards that govern the operation when implementing specific activities. Typically, control arrows carry information about the conditions under which the work must be performed. Every process should have at least one control arrow. In our case, the values of this type include: "Weather conditions", "Terrain limitations", "Command orders", "Operational situation".

The bottom side corresponds to the mechanisms – resources that carry out the work within the system. Mechanisms are not a mandatory component of the model and are represented at the discretion of the analyst. Values of this type can include: "Medical module", "Warehouse module", "Transport module", "Coordination management module".

The right side corresponds to the system's outputs – information and materials that result from processing the initial input data. Every process must have at least one output arrow. The context diagram I created depicts three such values: "Provision of medical care", "Consolidation and redeployment", "Reporting on combat losses".

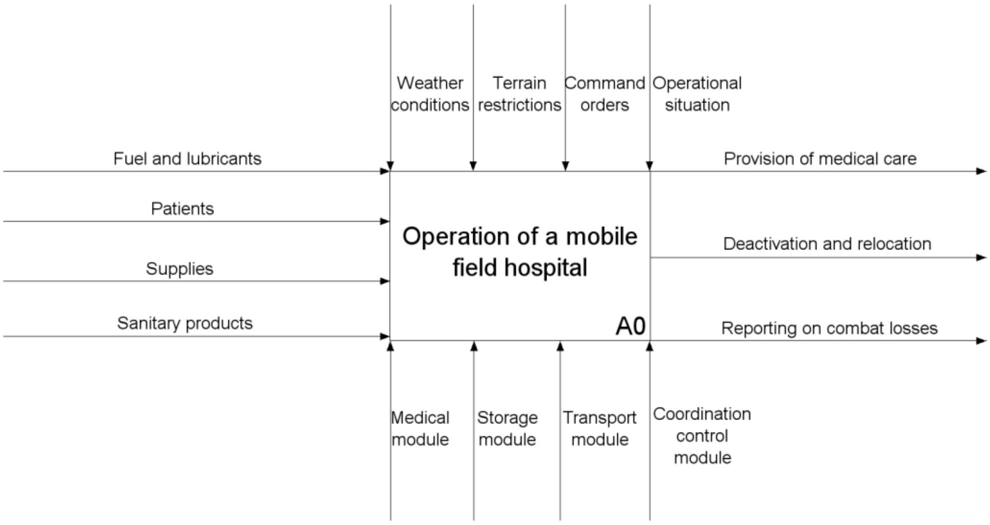


**Fig. 1.** Context diagram "Operation of a mobile field hospital"

In accordance with the conducted analysis, a UML use case diagram (Fig. 2) has been developed to display the main relationships within the system.

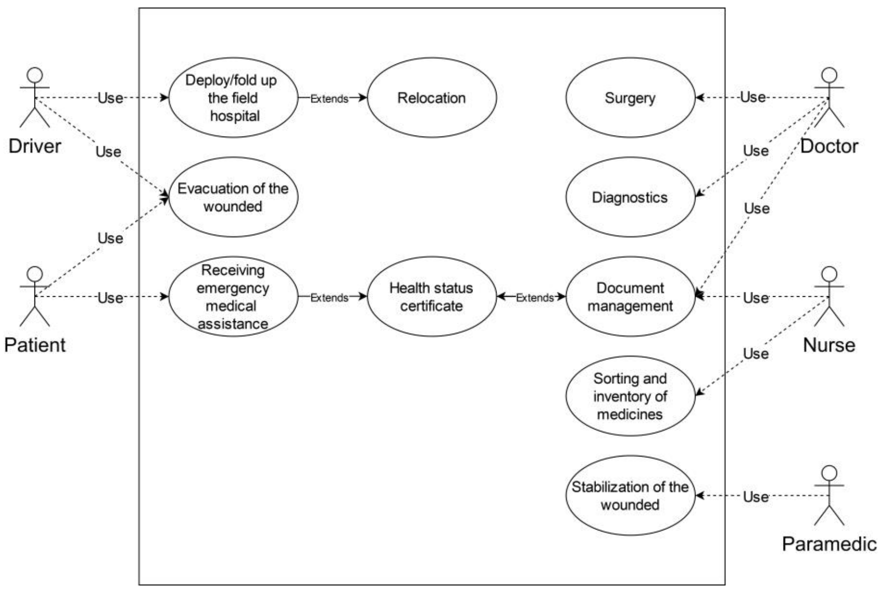


**Fig. 2.** UML use case diagram

This diagram provides a comprehensive understanding of who participates in the modular field hospital system and what functions are available to them within its framework. Additionally, it allows us to trace the chain of actions that are necessary for the execution of a specific operation. The sequence diagram enables the graphical representation of a use case scenario by displaying the sequence of actions exchanged between objects (Fig. 3).

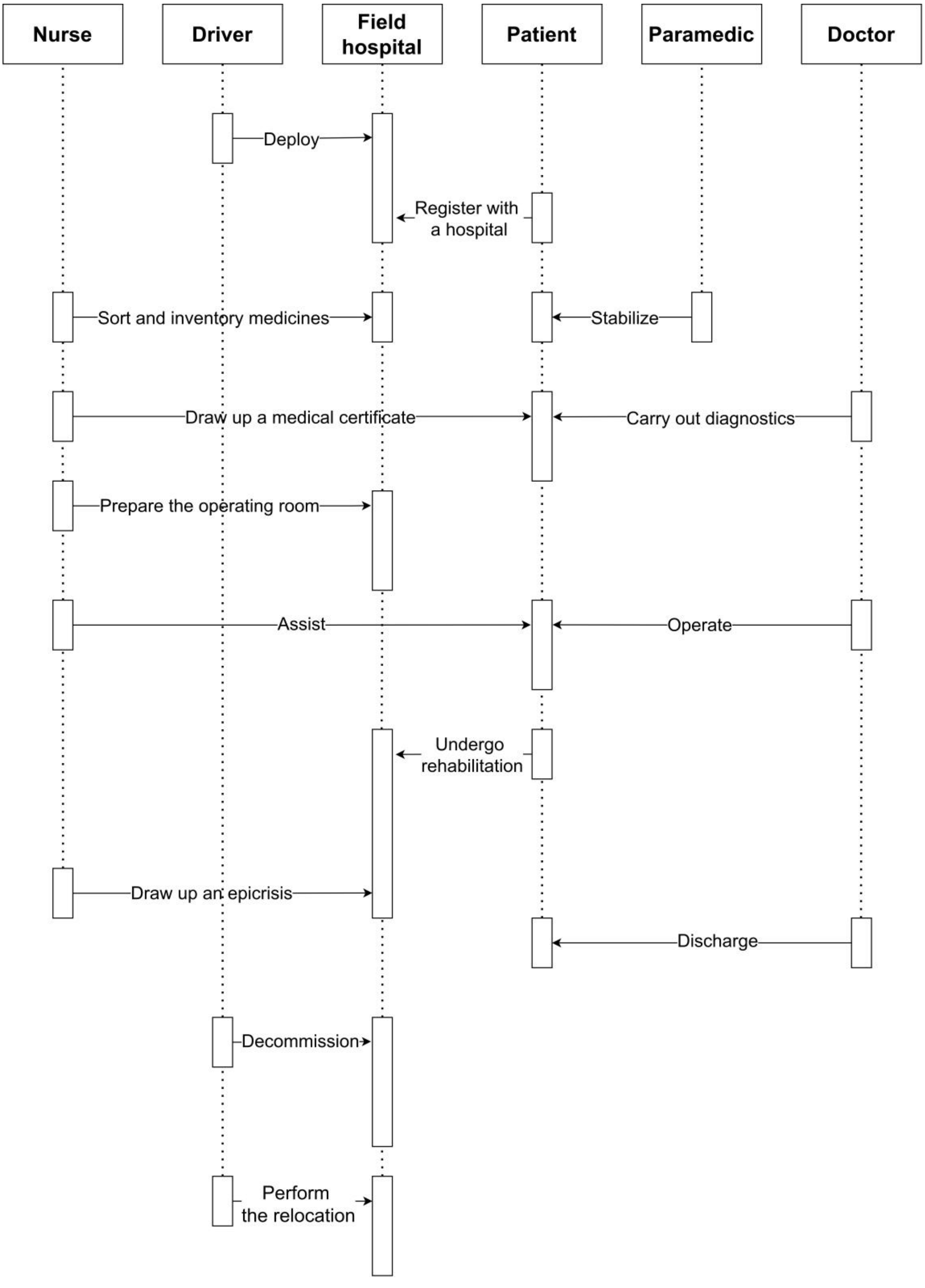


**Fig. 3.** UML sequence diagram

***Practical implementation.*** In the Autodesk Inventor modeling environment [13], standard 20-foot shipping containers have been designed. In my opinion, they are ideal, as their use aligns perfectly with the stated requirements for transportability, allowing them to be placed on a pre-prepared cargo truck and trailer platform. The stability of the structure is ensured by four outriggers. Control of these, as well as the overall electrical power supply, is managed via a special panel located in the corresponding box on the rear wall of the container. This system is entirely autonomous. As for scalability, these containers can be easily joined together by simply removing the doors on the right and left sides. The models themselves consist of multiple assemblies, which means they have many moving parts, allowing various usage scenarios to be presented during the modeling phase (Fig. 4).

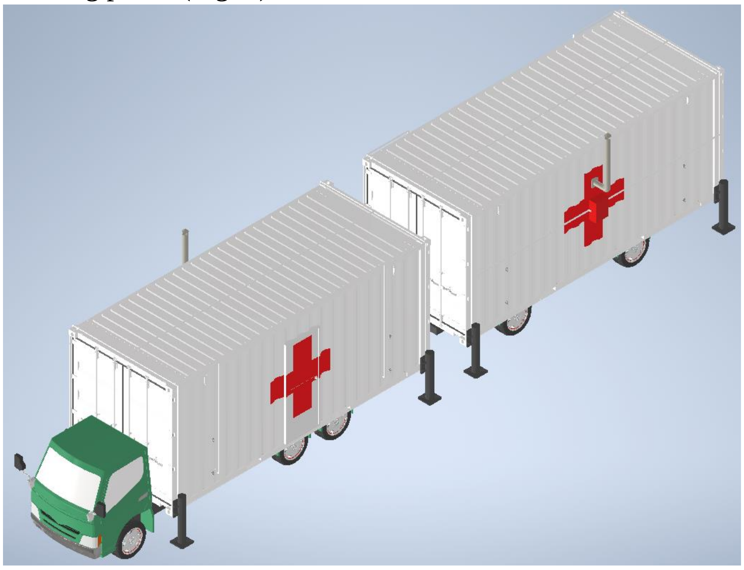

**Fig. 4.** Three-dimensional models of containers on mobile platforms

The internal layout of the containers has been modeled. To provide a clearer understanding, two configuration options have been designed: a patient room and a surgical department [14] (Fig. 5). In the first case, there are 2 bed spaces, nightstands, and IV drip stands for administering medications. In the second case, there is an operating table, a surgical lamp, a medical cart, and a cabinet with a cardiac monitor.

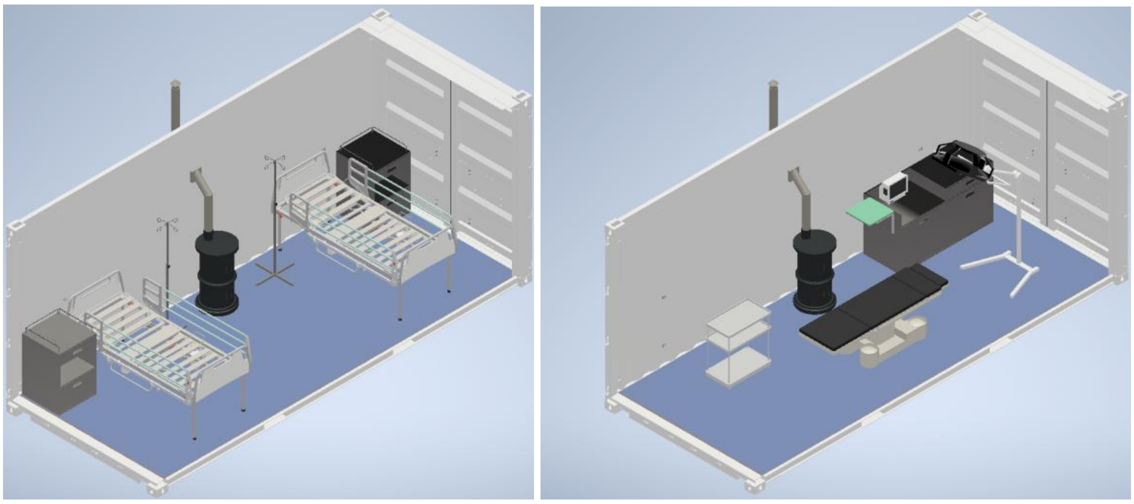

**Fig. 5.** Possible options for internal layout

The required room temperature can be maintained using either electric heaters or a metal stove placed in the center. Using Autodesk CFD [15], airflow simulations have been conducted (Fig. 6), as well as heating simulations of the stove during active use (Fig. 7). The container features four standard ventilation grilles on the top. Calculations have been made, and the results of the room aeration system simulation are presented in Fig. 8.

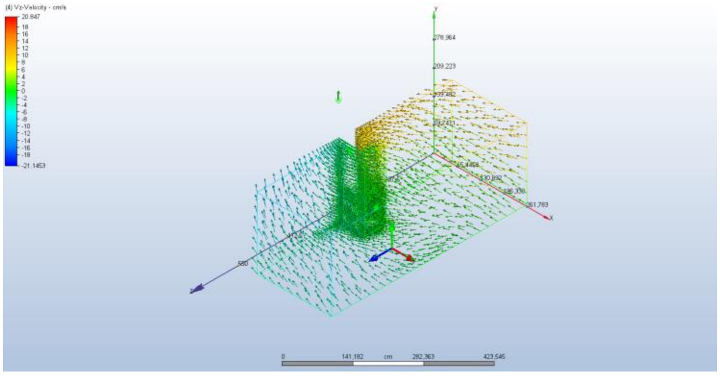

**Fig. 6.** Airflow simulation

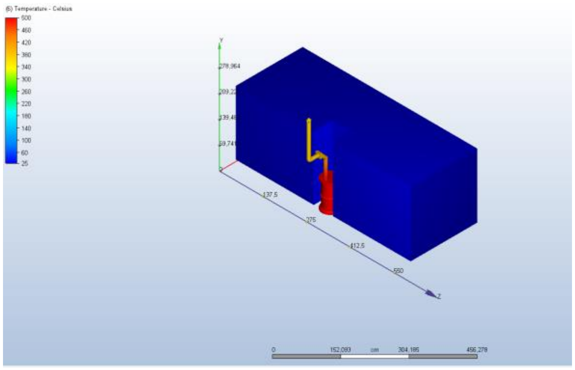

**Fig. 7.** Thermal analysis

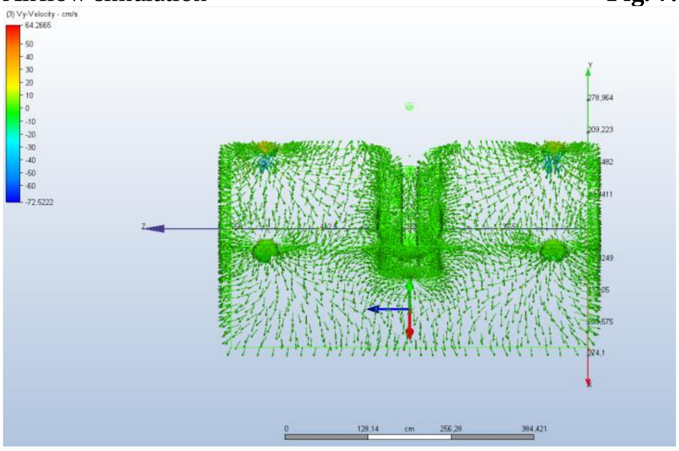

**Fig. 8.** Room ventilation

## Conclusions

A classification of hospital structures by their functional purpose has been carried out. The structural features of such technical solutions have been developed and described, with the main requirements, advantages, and disadvantages identified. A context diagram, UML use case and sequence diagrams have been implemented, allowing for the representation of the clear architecture, functionality, and interaction of the components of the designed system. Furthermore, in the solid and surface parametric design environment of Autodesk Inventor, modeling of all key links and nodes necessary for the design of mobile field hospital models has been conducted. The recreated models formed the basis for further analysis of physical processes, which, in turn, made it possible to determine the technical parameters of the proposed solution.

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## ПРОЕКТУВАННЯ МОБІЛЬНОГО ПОЛЬОВОГО ШПІТАЛЮ МОДУЛЬНОГО ТИПУ

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**Анотація.** У статті проаналізовано основні конструкції мобільних госпіталів та проведено їх класифікацію за функціональним призначенням. Розроблено та запропоновано базові тривимірні моделі з описом особливостей їх обслуговування. Визначено типові розміри конструкцій мобільних польових госпіталів. Наведено результати моделювання в середовищі Autodesk CFD.

**Ключові слова:** САПР, польовий госпіталь, Autodesk Inventor, Autodesk CFD, 3D моделювання, військова медицина.