Designing a Shelter Operating Room and Emergency Area for the Maternity Dnipro City Hospital

CAS Final Project Report

submitted as part of the study programme CAS Rebuild Ukraine

at the Bern University of Applied Sciences

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Bern, March 2024
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Table of Contents

Summary

We designed a concept for a new surgical unit within the existing bomb shelter adjacent to Dnipro Hospital №6. The unit will feature a modern, technologically advanced operating room and all necessary facilities.

The project emerged in response to the urgent necessity for continuous medical care during wartime conditions, recognizing that one of the most dangerous scenarios is an air raid. Unfortunately, even if a hospital in Ukraine is lucky enough to have a bomb shelter, it is not suitable for performing operations. Therefore, it is vital to equip hospitals with operating rooms in existing shelters.

Creating facilities for uninterrupted medical care during wartime conditions in existing bomb shelters addresses the needs of various parties involved in the healthcare sector, including hospitals, patients, their families, hospital management, staff, city authorities, and the wider community. Additionally, it aligns with the objectives of donors, Ukraine's recovery agency, and regulatory authorities.

With a connection to the hospital's management through one of our team members, we proposed to develop a layout for a surgical unit within the hospital's existing bomb shelter. Our goal was to develop a project that meets the requirements of medical technology and the specific needs of the hospital, while also remaining compact enough to fit within the shelter's existing space, and respecting its primary function of providing shelter during air raids.

For this purpose, we collaborated with Ukrainian architects specializing in healthcare facilities, and conducted interviews with doctors.

Since the objective of our project was to create a scalable solution applicable to other hospitals across Ukraine, we evaluated existing structures, primarily constructed during the Soviet era, to develop a flexible unit suitable for placement within widely used dimensional grids.

We also utilized the facilities and simulation technology of the SCDH to evaluate our layout at a 1:1 scale.

The key results achieved by our team in working on the project include the layout design of the existing shelter with a surgical unit, adaptable for use in other similar structures across Ukraine. Additionally, we successfully identified necessary facilities and equipment and established partnerships with producers in Switzerland and international organizations.

Moving forward, the project aims to obtain necessary permits, garner support from local authorities and sponsors for implementation in this specific hospital, and explore opportunities for broader implementation across Ukraine, ensuring sustained impact and resilience in healthcare infrastructure.

Our project highlights the effectiveness of collaboration and partnerships in addressing the current healthcare challenges in Ukraine. By engaging with doctors, hospitals, suppliers, and international organizations, we've established the foundation for safer, more inclusive, and sustainable healthcare in Ukraine. Through a shared vision and commitment, our aim is to ensure access to urgent healthcare services during wartime conditions for a greater quantity of patients.

Management Summary

Alla Oliinyk

A project lead.

- Developed a comprehensive project plan that outlines tasks, timelines, and resource requirements.
- Assigned tasks to team members based on their skills and expertise.
- Organized collaboration both within the team and with external partners.
- Facilitated communication about the project's goals, importance, and needs to stakeholders and partners.

Maksym Danyliuk

Architect

- Collaborated with a team of Ukrainian architects while designing the layout for the surgical unit
- Developed a concept for functional zoning
- Designed the idea and final version of the bomb shelter layout
- Worked on informational materials.

Metsger Maryna

Architect

- Together with Maksym Danyliuk developed the final version of the project's planning.
- Worked on various informational materials such as flyers, presentations, equipment lists, etc.
- Worked with other teams to provide them with information regarding our project.
- During the simulation at SCDH, was responsible for identifying and documenting issues and necessary adjustments.

Dmytro Vovk

Construction Expert.

- Gathered data for the project from hospital management and staff.
- Conducted an assessment of the project's compliance with Ukrainian state building codes.
- Facilitated a close cooperation with hospital’s management and staff during developing the layout for the surgical unit.
- Established communication with stakeholders, representatives of international organizations, and Swiss manufacturers

Kateryna Vynogradova

Communication Specialist

- Researched surgical equipment and furniture, including Swiss practices, necessary items, brands, models, and costs. Established communication with Swiss hospitals, particularly surgeons, for this purpose.
- Proposed and initiated the transfer of used but usable surgical equipment and furniture from Switzerland to Ukraine on a charitable basis.
- Organized collaboration with Ukrainian doctors for simulation in SCDH.
- Ensured project deadlines were met.

1. Introduction

1.1. Current situation in Ukraine's healthcare

Starting from 2014 onward, the Russian Federation has been systematically destroying Ukraine's medical infrastructure, beginning with the Donbas region, where over a third of its major healthcare facilities were destroyed as a result of hostilities[1].

On February 24, 2022, the Russian Federation launched a full-scale invasion in Ukraine, conducting relentless attacks that targeted civilian infrastructure, including hospitals, thereby committing war crimes. Throughout the first 35 days, Ukrainian healthcare facilities faced daily destructions[2], exemplified by the bombing of the maternity and children's hospital in Mariupol in just two weeks after the start of a full-scale invasion.

Now in 2024, a decade after the initial assaults on Ukraine, the healthcare infrastructure is still suffering from constant damage, medical workers are forced to work in dangerous conditions, and patients often do not have access to the medical care they need. According to the survey[3], conducted as of the beginning of December 2022, the third of Ukraine's population has experienced a shortage of medical services, with most of this third being concentrated on the southern part of the country.

As for this year, the Russian army is responsible for 1,475 attacks on healthcare, resulting in 112 fatalities and 224 injuries recorded[4]. Among casualties are 630 health facilities, impacting the treatment of an average monthly 454,768 individuals. Since the escalation of the war in February 2022, official reports indicate 27,768 civilian casualties, including women and children, with 9,806 reported deaths and 17,962 injuries, while it is acknowledged that the actual toll can be much higher[5]. Additionally, the Ukrainian population lives constantly under the threat of chemical, biological, radiological, and nuclear emergencies[6].

Due to the high number of attacks, constant air raids, and the ongoing threat of insecurity, Ukraine's healthcare system is currently in a state of major crisis and is incapable of fully meeting the needs of the population.

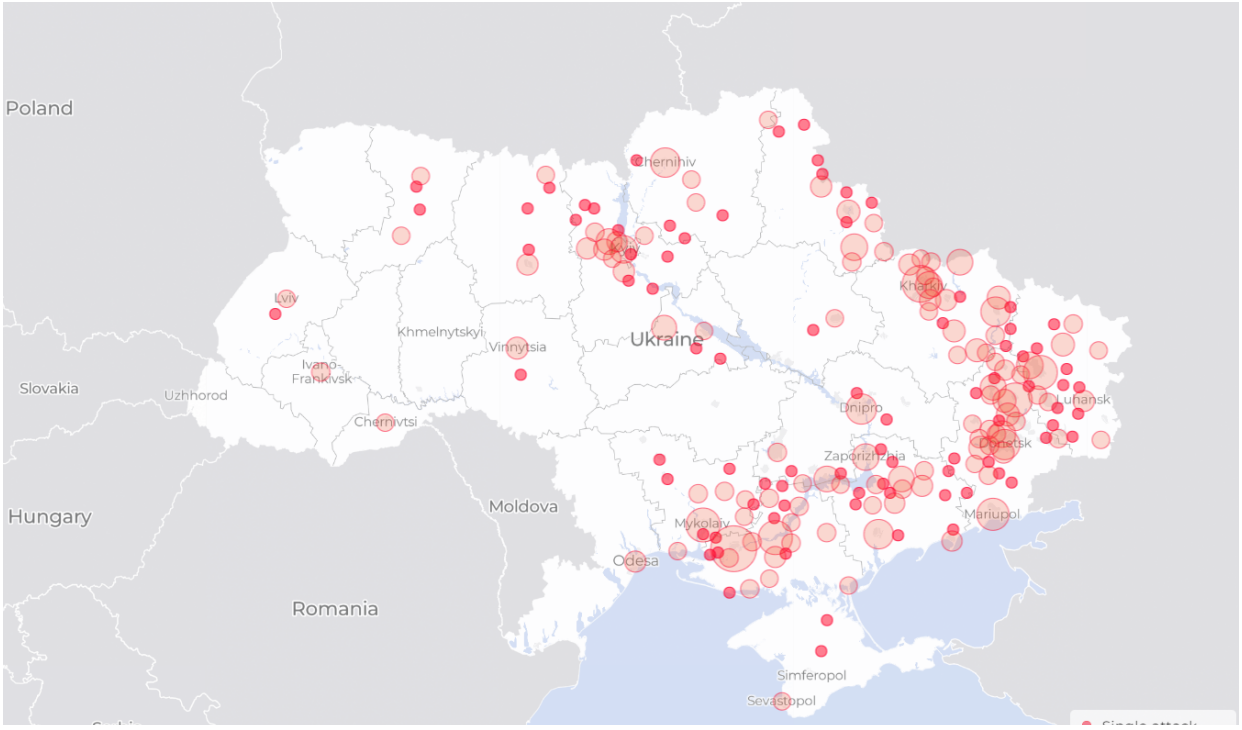


Figure 1. Attacks on Health Ukraine, 19 Nov. 2023. Source: "Attacks on Health Care in Ukraine." https://www.attacksonhealthukraine.org. Data as of December 31,2023.

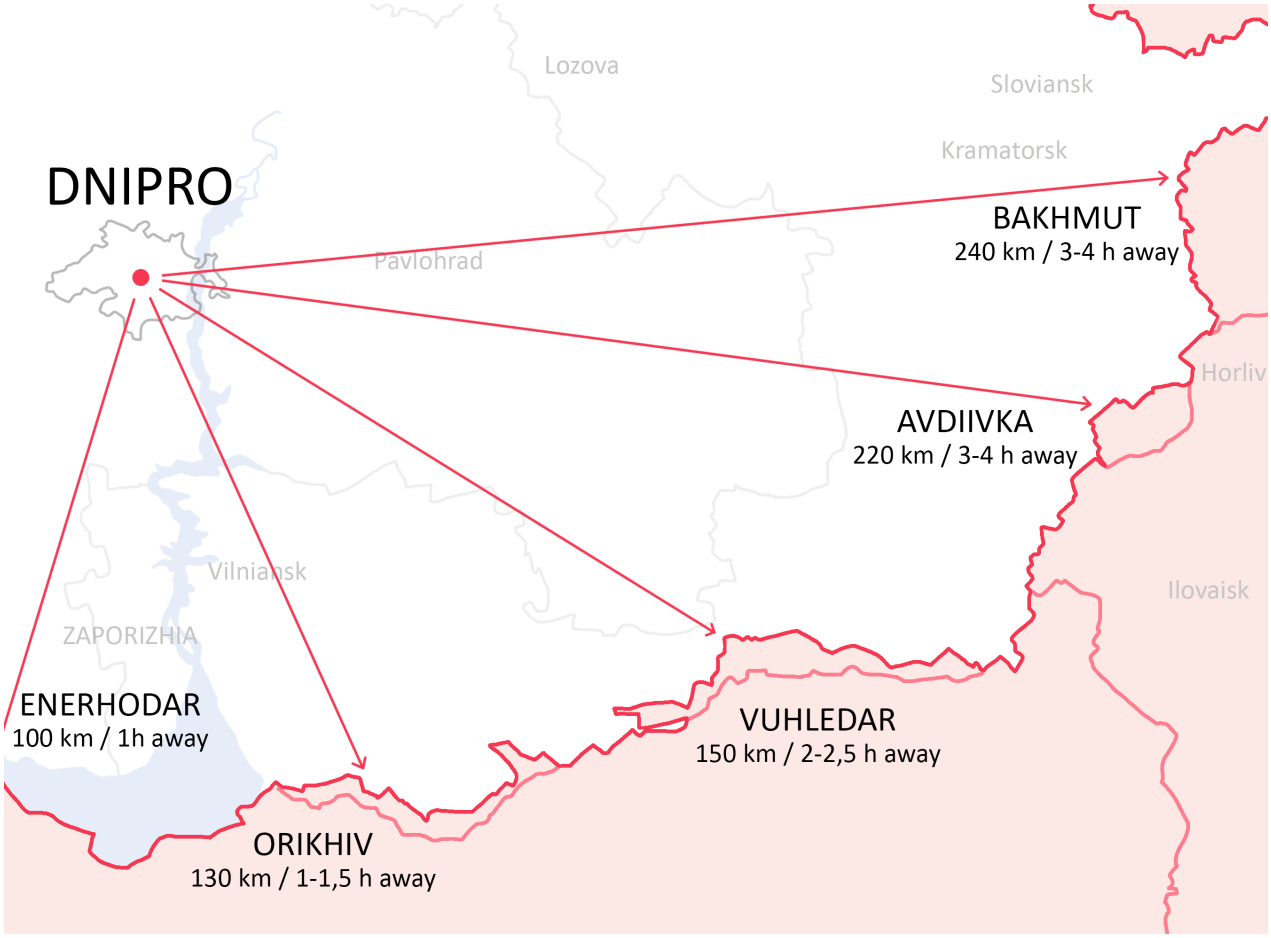


Figure 2. The distance from the city Dnipro to the front line hotspots

1.2. Situation in Dnipro

The maternity Hospital №6 is located in Dnipro, a major city in the south-eastern part of Ukraine, that is located extremely close to the military front line. The distance from this city to Enerhodar is only about 100 kilometres, and Avdiivka is just over 200 kilometers away. According to the latest statistics[6] among the accessible regions of Ukraine, the Dnipro region is currently in the 10 most war-affected areas, with over 16% of its healthcare facilities experiencing partial damage. It is constantly struggling with substantial or complete disruptions in primary care services and ongoing infrastructural damage. These figures show that due to its significant industrial importance, the city of Dnipro is now experiencing frequent missile attacks, and where the destruction of healthcare facilities occurs almost daily, which leads to patients in need having less and less access to the medical care they seek. At the same time, the hospital must admit civilian patients who have been seriously injured and military patients brought directly from the battlefield.

As per the data[7], the Dnipro region is ranked 4th in the frequency of air alarms during the war, registering a total of 2913 instances. It also has 4th position in terms of duration of air alarms, accumulating 2268 hours. The average time of air raids in Dnipro is approximately 38 minutes, with the longest one lasting for about 8 hours. Due to the number and duration of air strikes daily and the danger during these attacks, medical workers are unable to work constantly above ground in hospital buildings. But it is then that injured people are often brought in for emergency medical care and surgery. Therefore, doctors must go to the basements and work in improper conditions or perform operations during an attack in dangerous settings.

The hospital's medical staff and patients need a safe place to stay during air strikes, to continue working and performing operations in safety. Because of the severe damage to medical infrastructure and the dangers of being above ground, it is important to have a safe place underground and close to the hospital that is customized to the needs of the medical facility.

2. Project Goals

Dnipro Hospital No. 6 was built in 1989. It accommodates 339 patients, with 215 beds dedicated to surgery and employs 129 staff members.

In 2023, the hospital treated patients according to the following specialties:

- Surgical beds: 4,901
- Traumatology: 4,576
- Urology: 2,013
- Proctology: 1,441

Total: 12,931 treated patients.

The hospital has a nuclear bomb shelter connected to it through a tunnel. During an air raid alert, this bomb shelter must fulfil two functions:

- Serve as a shelter for hospital staff.
- The premises of the operating room and necessary facilities for performing surgeries must be equipped.

However, due to the lack of necessary infrastructure in the bomb shelter, the following problems arise:

- Inadequate spaces complicate the work of surgeons.
- Deterioration of hygiene conditions due to the absence of flow divisions, rooms according to the level of sterility, specialized areas for sterilization, and preparation of doctors for surgery.
- Lack of suitable conditions for post-operative patient care.

Figures 3, 4. Current Current state of the shelter

Since one of our team members, Dmytro Vovk, has a connection with the hospital's management, our team proposed a collaboration with the hospital. The aim of this collaboration is to develop a floor plan for the surgical unit within the shelter and seek support from international sponsors.

As participants in the CAS Rebuild Ukraine study program, our objectives extend beyond this specific case to address broader issues outlined in Chapter 1. Thus, our project goals are as follows:

- Develop a surgical unit layout adaptable for similar existing structures, predominantly constructed during the Soviet era.
- Establish strong connections with sponsors and explore funding opportunities for the project.
- With the help of this project, draw attention to the critical absence of safe underground facilities for surgical procedures, essential for providing uninterrupted medical care, particularly in wartime conditions.

3. Methodology

3.1. Participants

Parties involved in the development of the project included:

- Our CAS Rebuild Ukraine team, which includes architects.
- The architectural firm "Architec-Expert" from the Ukrainian side.
- Hospital management and staff, including surgeons.
- Ukrainian doctors currently residing in Switzerland.

3.2. Key Components of our approach:

- Stakeholder analysis.
- Assessment of medical technology requirements and hospital staff needs.
- Architectural design.
- Using the simulation technology of the Swiss Center of Design and Health (SCDH).

3.2.1. Stakeholder analysis:

- The major beneficiaries, or stakeholders, of our project are:
- Hospitals patients and their families
- Hospital management
- Hospital staff
- City authorities and community
- Donors
- Ukraine’s recovery agency
- Regulatory authorities

3.2.2. Assessment of medical technology requirements and hospital staff needs

With the assistance of an architect from "Architec-Expert" who conducted a series of interviews with hospital staff, we gained insights into the specific needs of the hospital regarding the shelter surgical unit. This included considerations such as functionality, premises interconnection concerning medical technology, medical hygiene requirements, and the unique challenges of operating during wartime.

3.2.3. Architectural design

The "Architec-Expert" team assessed the existing bomb shelter structure and determined its suitability for housing an operating room. The ceiling height, a primary constraint, was found to be meeting the minimum height requirement according to Ukrainian Building Codes[9]. Additionally, the Ukrainian team created a measurement drawing of the structure to aid in the design process.

Having gathered all necessary information, our architectural team began developing a floor plan for the surgical unit within the existing bomb shelter structure.

During the design development phase, we utilized the expertise of the Ukrainian architect in the following ways:

- Functional zoning, considering medical processes.
- Ensuring compliance of the design with Ukrainian construction and sanitary standards[9, 10].
- Placement of equipment in accordance with medical technology requirements.

3.2.4. Using the simulation technology of SCDH

Partnering with the Swiss Center for Design and Health (SCDH) allowed us to test and refine our ideas through simulation.

This process involved two key components:

- Utilizing the SCDH Living Lab's extended reality simulation area, SIM^{XR}, our floor plans were projected in their original size. Using modular partitions, our team constructed walls according to the projection, resulting in a layout of our project on a 1:1 scale.
- Doctors from the Dnipro hospital proposed various scenarios for operating modes within the surgical unit. Ukrainian doctors residing in Switzerland guided our team through simulating these scenarios in the Living Lab. Dnipro hospital staff and architects from Ukraine participated remotely using a robot equipped with a camera and microphone. Together, we recreated proposed scenarios within our full-scale model, using equipment provided by SCDH. Feedback from doctors and architects based on the simulation results allowed us to make necessary adjustments to the layout.

Figure 5. Simulation at SCDH, Living Lab: Shelter's projected floor plan

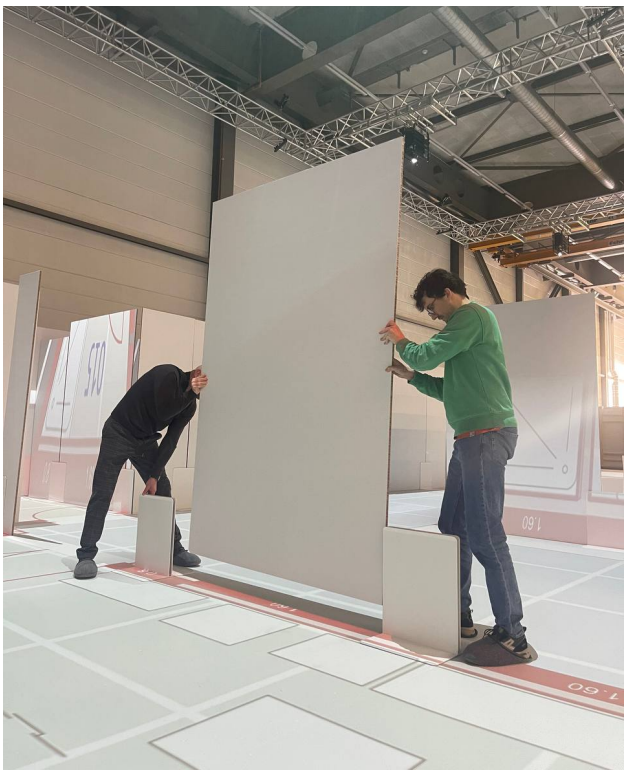


Figure 6. Simulation at SCDH, Living Lab: Constructing the partitions

4. Project Result

4.1. Existing structures study

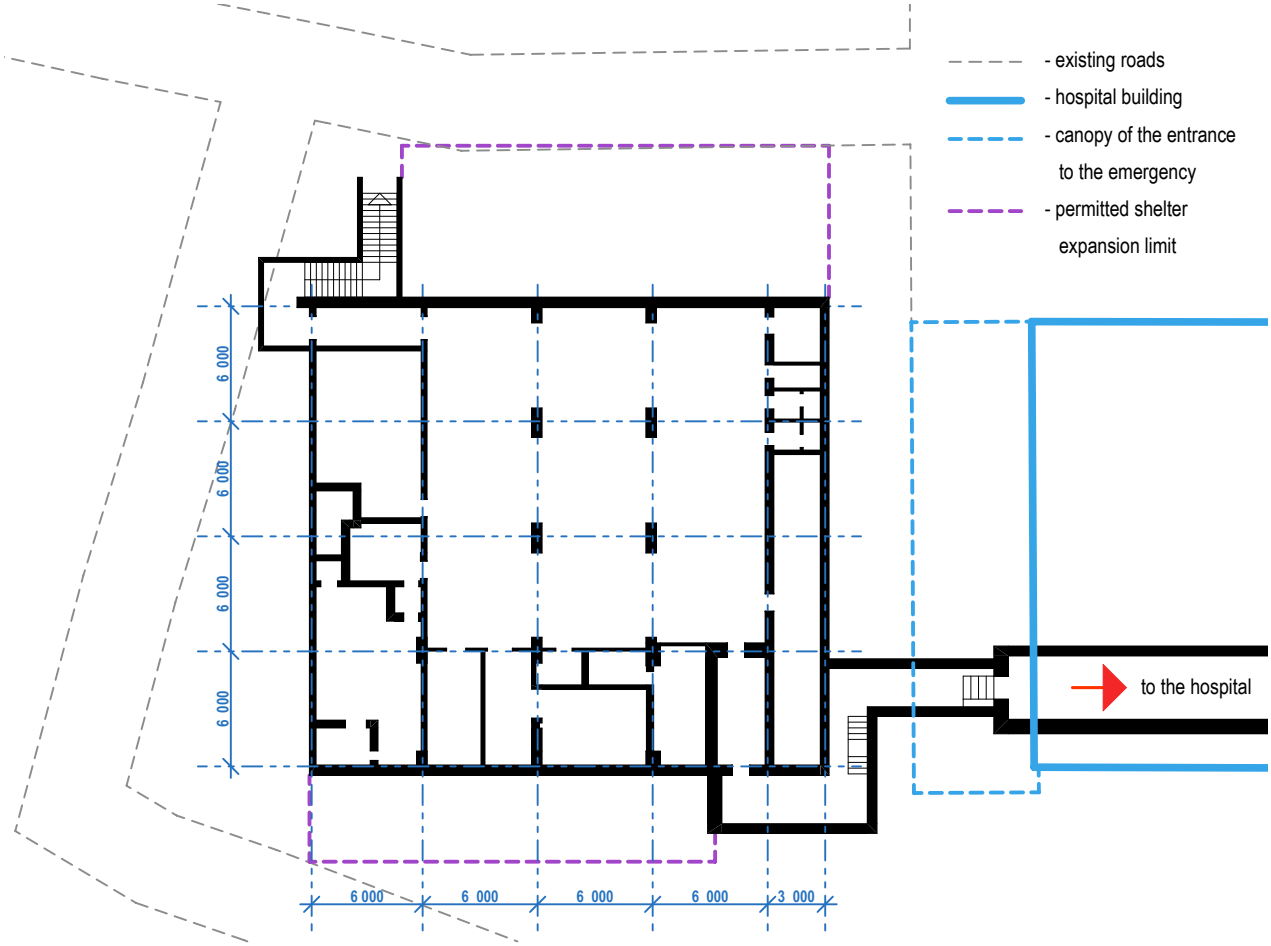


Figure 7. Shelter's floorplan. Current state

The distance between the axes of the bearing elements within the existing structure, including pillars and walls of the main premises, measures 6 meters (Figure 7), a standard construction module widely used during the Soviet era (Figure 8). Accordingly, we decided to design the size of the rooms and their placement with consideration for this module. This approach allows for the creation of a unified premises unit suitable for structures with similar module sizes.

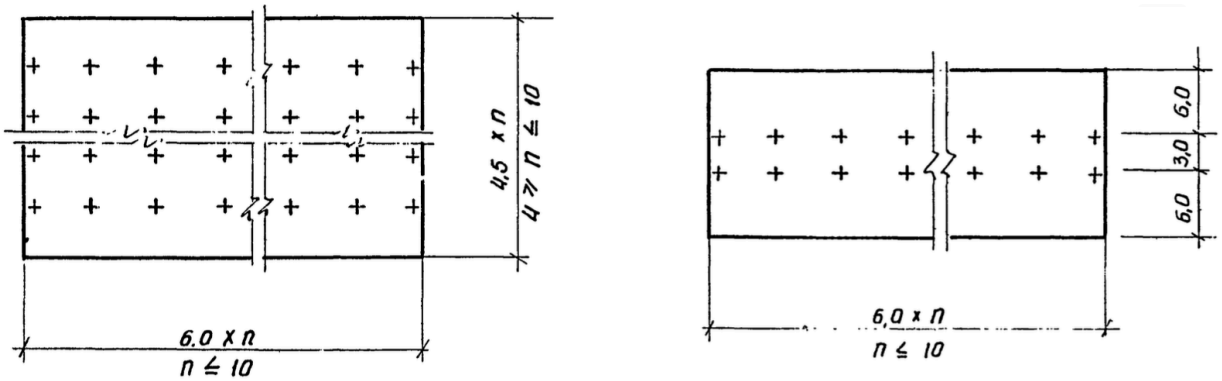
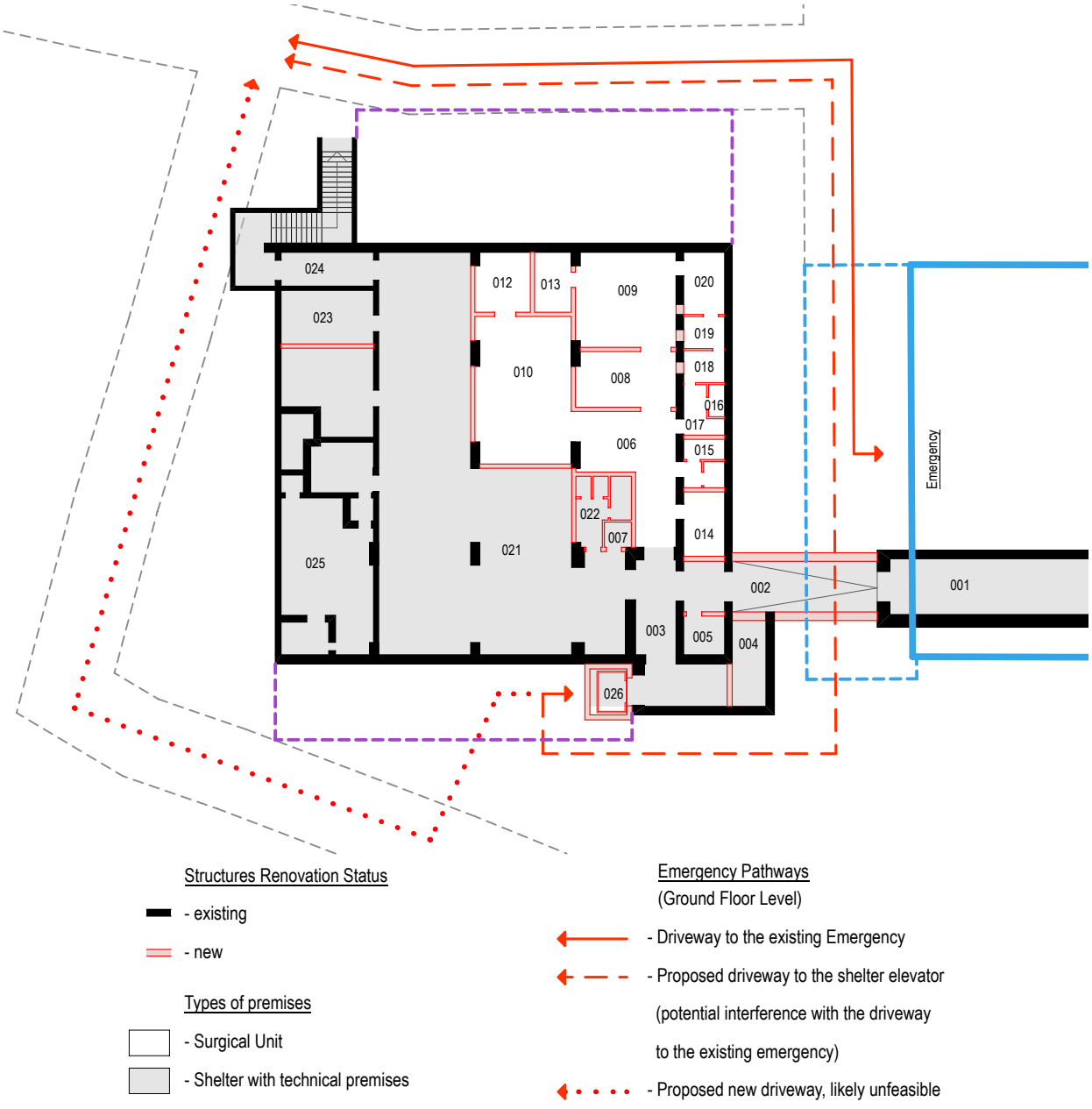


Figure 8. Example of typical modular shelter floor plans, as described in the Soviet Design Guidelines[8]

4.2. Initial Floor Plan Considerations and Subsequent Challenges

Initially, to optimize costs, the floor plan was entirely located within the existing structure, eliminating the need for new wall construction. Subsequently, this floor plan version presented two primary challenges:

- Interference with Emergency Driveway: It became apparent that the proposed placement of the elevator could potentially interfere with the emergency driveway, necessitating a reassessment of the layout.
- Feasibility of Proposed New Driveway: Additionally, the feasibility of introducing a new driveway was called into question due to potential logistical and structural constraints.



001 - Tunnel 1, 002 - Tunnel 2, 003 - Gateway, 004 - Storage, 005 - Storage, 006 - Corridor, 007 - WC Handycap, 008 - Induction, 009 - Operating, 010 - Intensive care, 012 - Washing, 013 - Sterilisation, 014 - Storage, 015 - WC-Shwr. Nurces, 016 - WC Surgeon, 017 - Dirty Clothes, 018 - Shower, 019 - Dressing Clean, 020 - Preoperating, 021 - Shelter, 022 - WC-Shwr. Shelter, 023 - Storage, 024 - Gateway, 025 - Technical, 026 - Elev.

Figure 9. Initial Floor Plan

4.3. Refined Floor Plan Layout

After discussing the initial layout with the Ukrainian architect's team and assessing it through simulation at the SCDH Living Lab, we created a refined version of the layout. This included the construction of a new extension to free up the existing corridor to provide access to the elevator.

The refined layout introduces the following major improvements:

- The elevator to the ground floor is now located in a broader area near the parking and closer to the entry to the hospital's territory.
- The link of premises "Induction – Operating Room – Intensive Care" now functions in one direction, aligning better with staff requirements.
- Direct access to the emergency stairs has been obtained.
- A larger shelter area has been secured.

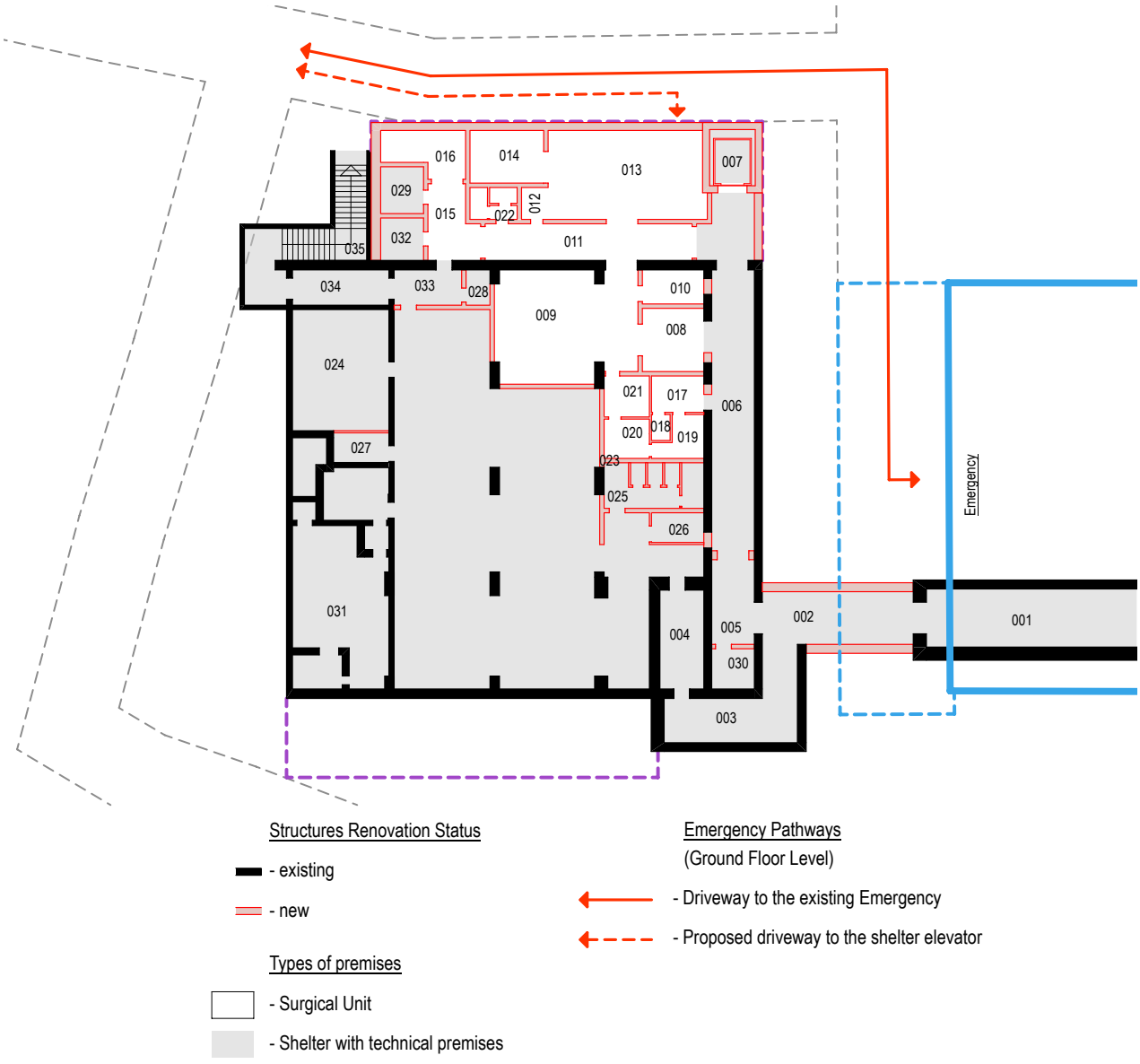


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Figure 10. Refined Floor Plan

4.4. Medical equipment

The Ukrainian team interviewed hospital doctors to define the list of necessary medical equipment and its preliminary arrangement in the premises.

This arrangement was later assessed during simulations in Living Lab at SCDH, and needed corrections were made.

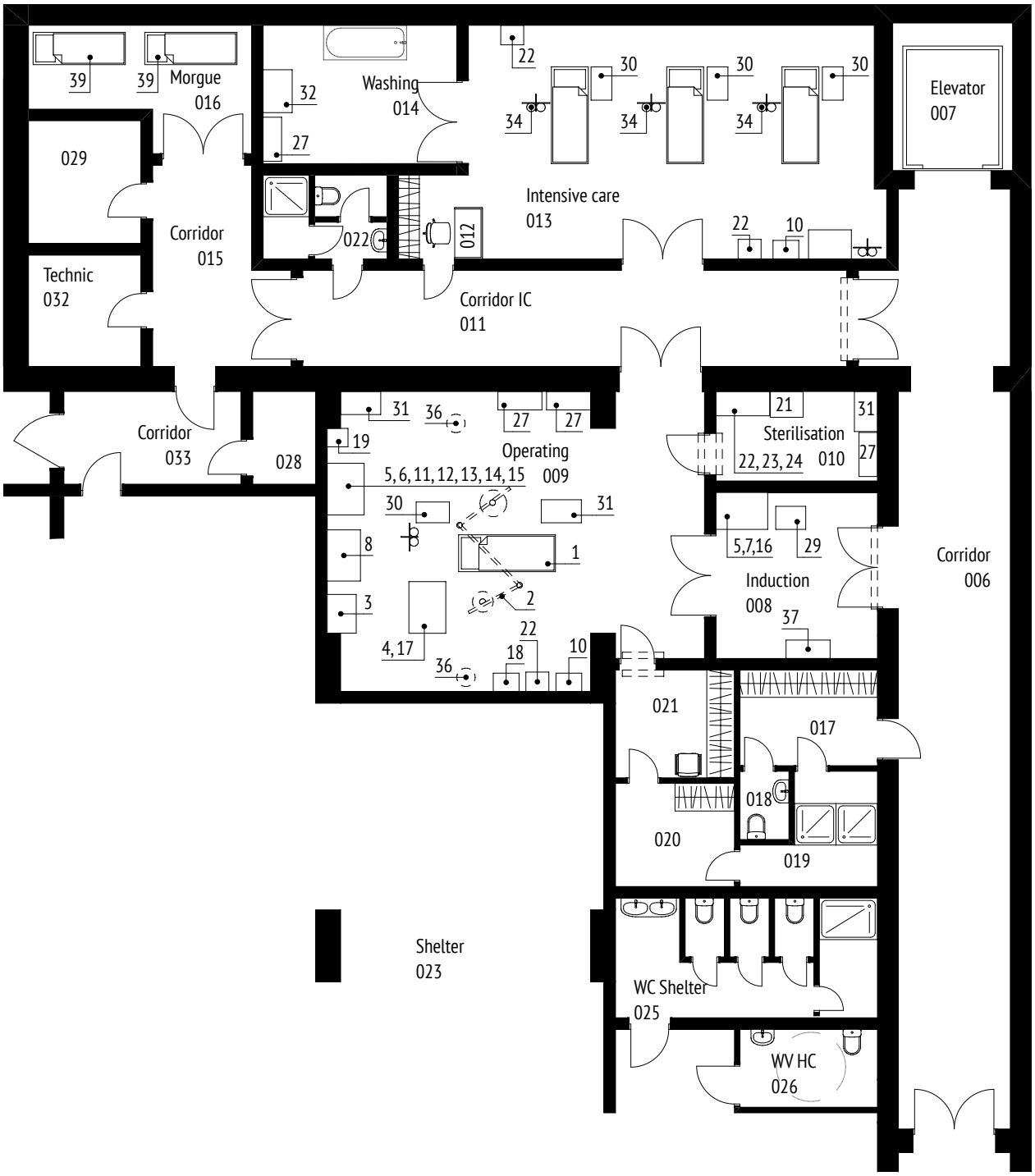

Figure 11. Layout plan of medical equipment

Equipment

№	Item	Qt.	Dimentions, mm
1	Universal table	2	2100 x 800
2	Dual-dome surgical lamp	1	ø dome 500
3	Anesthesia and respiratory unit	1	839 x 628 x 1386 (h)
4	Modular patient monitor	2	318 x 264 x 152 (h)
5	Pulse oximeter	2	
6	12-channel electrocardiograph	1	
7	Medical air compressor	1	412 x 442 x 400 (h)
8	Refurbished ultrasound diagnostic system	1	
9	Mobile Cart	2	
10	Artificial lung ventilation apparatus	2	
11	Modular syringe pump	3	214 x 134 x 94 (h)
12	Infusion pump	1	
13	Oxygen concentrator	1	900 x 515 x 1350 (h)
14	Defibrillator	2	25 x 28 x 9
15	Endoscopic rack	1	400 x 450 x 2000
16	Surgical electrocautery	1	
17	Medical aspirator	2	460 x 420 x 850 (h)
18	X-Ray		
21	Ethylene oxide sterilizer	1	560 x 710 x 720 (h)
22	Medical waste disposer	4	
23	Electric sterilizer	1	270 x 130 x 65
24	Automatic endoscope washing and disinfection machine	1	90 x 75 x 120 (h)
25	Bactericidal irradiators	6	925 x 53 x 81
27	Medical cabinet SM-2	5	400 x 955 x 1610 (h)
28	Coat cabinet SHM	2	500 x 400 x 1620 (h)
29	Anesthesia table	2	650 x 500 x 780-1000 (h)
30	Bedside table ST-T	3	720 x 450 x 800
31	Universal table ST-UT	3	870 x 500 x 995 (h)
32	Procedure table	1	930 x 630 x 470 (h)
33	Hand surgery table	1	520 x 460 x 700 – 900
34	IV stand	6	2000 (h)
35	Medical table	1	600 x 1000 x 750
36	Medical chair	7	Ø 400
37	Anesthesia complex	1	400 x 955 x 1610 (h)
38	Universal gurney	2	600 x 2000 x 750 (h)
39	A table for corpers	2	600 x 2000 x 750 (h)

4.5. Simulation in the Living Lab, SCDH

With the help of simulation, various flows and processes within the projected floor plan can be evaluated and optimized. Our team, together with the hospital staff, created several possible scenarios during air alarms.

4.5.1. Scenario for simulating medical staff actions

- “Patient 1” (lying, moving along the patient's flow path (red)) is being moved into the induction room.
- “Patient 2” (can sit up, moving along the patient's flow path (red)) needs an emergency surgery and is being moved into the induction room together with the “Patient 1”.
- “Patient 3” (can sit up, following the path of the staff (green)) is already anesthetized, has a blood loss but has a high probability of survival.
- “Patient 4” , close to death, has a small chance of survival (moving along the surgeon’s flow path (blue)).
- Doctors and staff make the same journey.
- “Patient 1” and “Patient 2” are being moved to the operating theatre after anesthesia.
- “Patient 4” is waiting in the corridor near the induction room.
- “Patient 3” is taken to the intensive care unit and is waiting for the operation.
- As “Patient 1” and “Patient 2” are being operated on, “Patient 3” enters the operating theatre, while “Patient 4” is being anesthetized.
- One by one surgeries are performed and all patients are taken to intensive care.

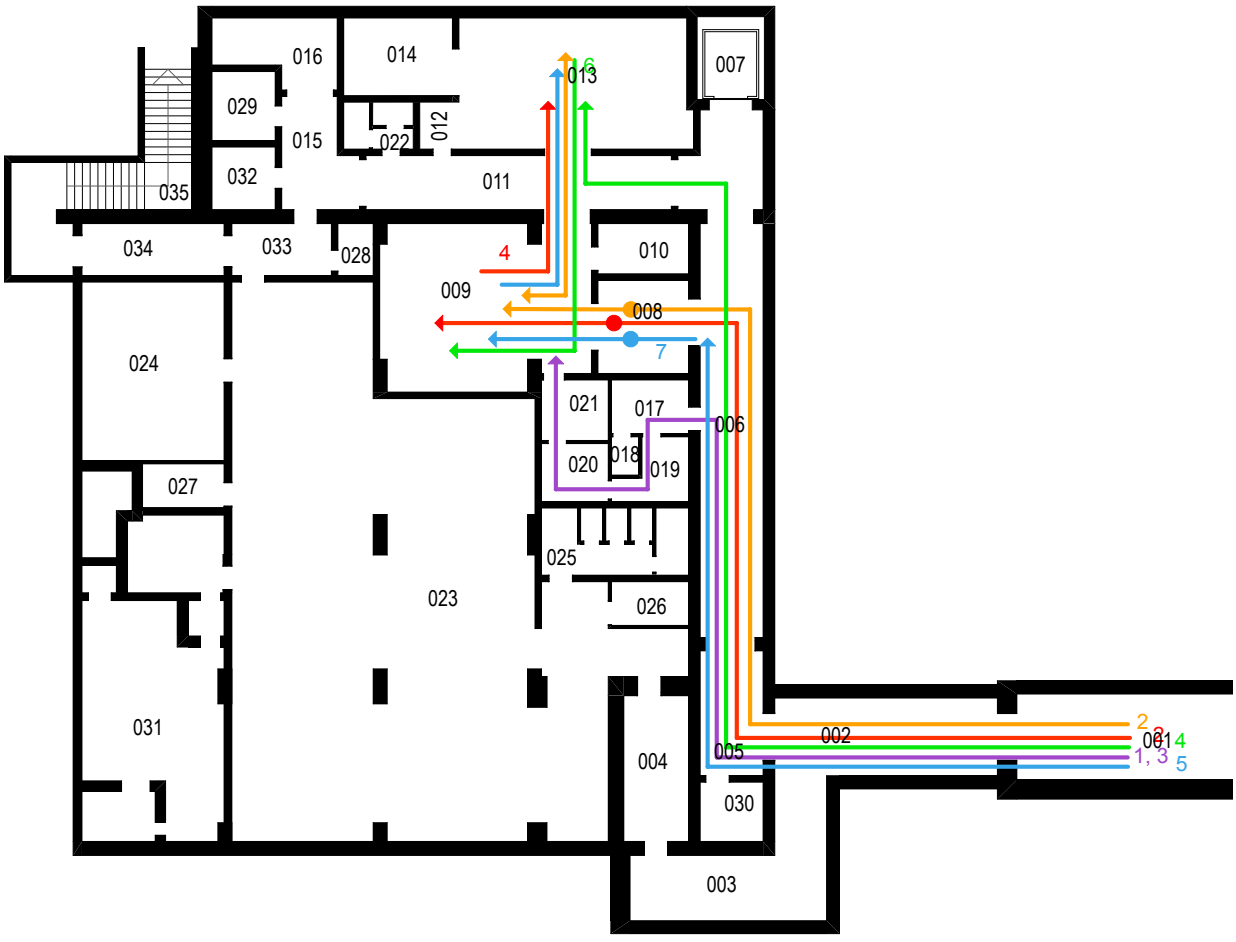

Figure 12. Flows scheme

4.5.2. Conclusions drawn based on the simulation

The layout, including room relationships, aligns with the requirements of the medical staff, allowing for the possibility of servicing multiple patients simultaneously (the simulation assumed work with 4 patients). During the simulation, the medical staff assessed the feasibility of installing a second operating table and concluded that it is possible. The arrangement of medical equipment should be adjusted based on the findings after the simulation.

4.6. Functionality

The proposed layout ensures functional separation between the bomb shelter and the operating block. The widths of corridors (2,4 m) and the sizes of the surgery unit's rooms comply with the building norms of Ukraine[9]. There are rooms for surgeon preparation before surgery. The operating room is designed for conducting intracavitary interventions at one operating table (excluding auxiliary premises), in addition to operating rooms for neurosurgical, orthopedic, and cardiothoracic surgical interventions.

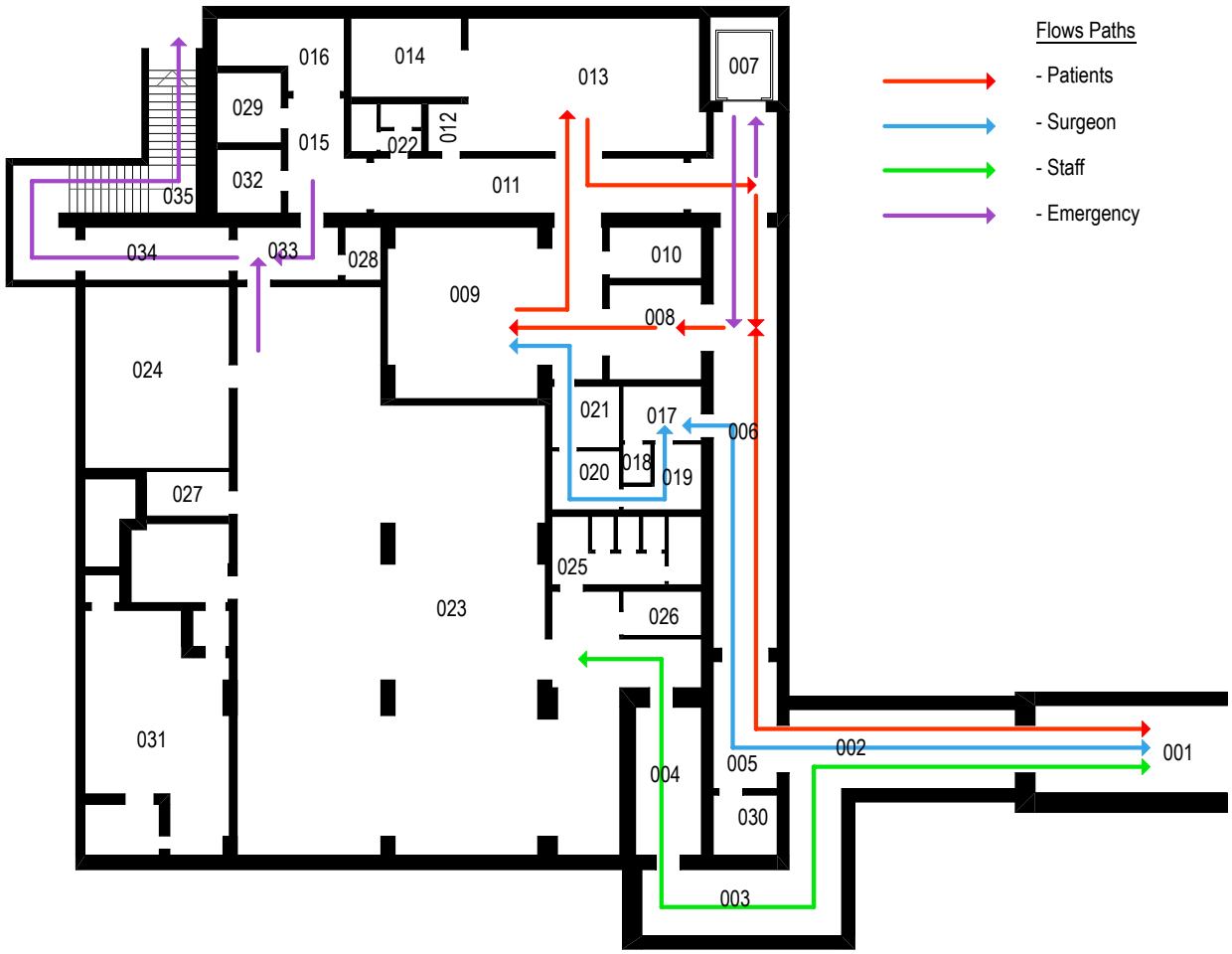

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Figure 13. Diagram of flow patterns for various groups

5. Discussion of next steps. Vision for Implementation

5.1. Currently we see the following steps to implement our project:

- Presentation of our project within the CAS framework
- Attracting information attention, both in Switzerland and in Ukraine
- Our partners in Ukraine, based on our design work and the expertise of our Swiss partners, are developing a detailed working design for a bomb shelter with an operating room. After that, estimate documentation is developed and undergoes a state examination, which confirms compliance with construction standards and confirms the cost of work and equipment.
- Having a ready-made project with a detailed cost of construction work and the cost of equipment, we will be ready to present it to International organizations and the government of Ukraine and Switzerland to bring it to life.

5.2. Partnerships

In this section, we will outline our implementation plan for developing partnerships with:

5.2.1. Doctors from Ukraine and Switzerland

Ukrainian doctors have informed us about the situation in Ukraine, identified issues with the detailing of aspects, and determined strategies for addressing existing problems and assisting Ukraine during both military and post-military periods. Swiss doctors play an important role in the partnership by providing their assessment, consultation on technological progress, and possible solutions that Ukraine currently faces in the medical field.

5.2.2. Hospitals in Ukraine and Switzerland

The Ukrainian side actively collaborates with us, providing all the necessary data for calculating the architectural aspects of the project, indicating cultural needs in medical institutions, and shaping them through the regulatory framework of Ukrainian legislation. Swiss hospitals play a key role in the partnership through openness and readiness to provide informative assistance, visual familiarization with the principles of work of doctors and medical personnel in comfortable medical facilities (buildings), provision of information on medical equipment, surgical instruments, and furniture for operating rooms, as well as substantiation and layout of the main points in this matter.

5.2.3. Medical Equipment Suppliers and Key Stakeholders in Switzerland

Apart from suppliers, we recognize the value of partnerships with other stakeholders, such as healthcare institutions, research organizations, technology providers, and companies supplying medical equipment and furniture. We strive to establish strategic collaborations with these firms and organizations to leverage their resources, expertise, and networks for mutual benefit. This may include joint development projects, knowledge exchange initiatives, or collaborative marketing events.

Currently, all collaboration goals have been achieved to bring our project to life. However, we also envision ongoing collaboration after the project is completed, as many medical institutions built within a certain timeframe have a similar building typology, which allows for the scalability of this project.

Additionally, during the collaboration process with Swiss doctors and medical institutions, the issue of further developing a strategy for charitable donation by Switzerland to Ukraine of used but perfectly functional equipment and furniture for operating rooms, intensive care units, and patient hospitalization rooms was discussed instead of disposal in Switzerland. This issue will receive special attention in the future.

5.3. Implementation plan

One of the first steps of the implementation plan is the presentation of the project, with the support of CAS Rebuild Ukraine.

After that, the necessary step for the next stages is the Ukrainian side, namely our partners in Ukraine, "Architectural Bureau Arhitek Expert," who will develop a detailed working design based on our project and the expertise of our Swiss partner SCDH. It will include calculations of the cost of work and equipment that are necessary for the realization of the project. The section related to the equipment may have a slightly different look if we achieve the result of receiving used equipment as a gift but in proper working condition from Switzerland to Ukraine, which will significantly approach our performance result with a huge reduction of the required budget. For this purpose, it is planned to present our project to the local government of Switzerland, where information about the project will be placed through information campaigns with the attraction of interest and possible various participation of local organizations and enterprises. We do not exclude or actively search for sponsors.

Having received the appropriate data calculation, the hospital management will be able to obtain the government expert opinion necessary to obtain a construction permit, which will allow them to officially apply to the local governments of Ukraine and international donors to implement the project.

While working on the development of the project, we have already talked with representatives of international organizations such as the Red Cross of Ukraine and the World Health Organization, and we have also prepared a list of organizations that could take part in the construction of this necessary facility. We also plan to turn to the following organizations for help:

- The UN Program for Reconstruction and Peacebuilding announces a grant for the development of mutual aid groups in eastern Ukraine.
- The United Nations in Ukraine is the United Nations.
- All-Ukrainian Charity Fund "Peace and Goodness"
- International BF "Health of the Ukrainian People"
- Programs (GIZ) to help Ukraine, etc.

Many medical centres, which were built in a certain time period, have a similar architectural plan or are built according to a template, which makes it possible for this universal plan to be scaled up and further implemented. The universal plan simplifies and reduces the costs of implementation, which makes it more attractive for Switzerland and Ukraine. This project is relevant not only during the reconstruction of Ukraine but also during the war period. It is extremely necessary and does not require cancellations. We also plan to introduce the project to the local government of Ukraine, as despite the large percentage of investments in the military, defence, and medical sectors, the project still needs support and donations for such projects.

6. Conclusion

The project aimed to address the critical need for a functional surgical unit within the given bomb shelter, which during an air raid alert, must serve as a refuge for hospital staff while also providing facilities for surgical procedures.

Our methodology involved assessment of medical technology requirements, architectural design, and utilization of simulation technology from the Swiss Center of Design and Health (SCDH). Through collaboration with the hospital management, medical staff, Ukrainian architects and the SCDH, we were able to develop a refined floor plan that meets the needs of both medical staff and patients.

By means of technology and partnerships, we aim to contribute to the enhancement of medical facilities and services in Ukraine.

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- Galenko Volodimir, surgeon
- Yushchenko Igor, deputy medical director, traumatologist.

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- Dr. Roksolana Korolevych, Obstetrics and Gynecology
- Dr. Valentyna Koptel, Anesthesiology

Declaration of Generative AI and AI-assisted technologies in the writing process

We used Generative AI and AI-assisted technologies to search for optimal phrasing and automatically check for grammatical errors during the writing process.

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