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Interference between Land and Sea Logistics Systems. Multifunctional Building System Design Towards Autonomous Integrated Transport Infrastructure

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ABSTRACT: The research is focused on developing design theory towards efficient multifunctional facilities for logistics supply chains in the contemporary urban city structures. The development of modern systems based on autonomous transport creates new conditions for their management and generates an emerging need to define dedicated functional service structures. An important element of consideration also taken into account is the scenario for large-size unmanned facilities operation in the multifunctional port facility and its connections to power supply from renewable energy sources. Despite the high degree of complexity, modern transport solutions should be focused on optimizing the distribution time and trans-shipment time within the intermodal supply chain as well as provide ecological logistic solutions. Due to the large number of system components, the study presents a simplified database structure allowing for a comprehensive technological overview within the entire system.

1 INTRODUCTION

Contemporary conditions and opportunities related with the development of logistics system are in the middle of a complex socio-economic functional space. Activities in the field of space management are focused on the implementation of principles of sustainable development. We are currently observing the moment when the implemented systems are aimed to create more economic, ecological and socially acceptable solutions. There are few milestones within the technology development which are defining the future shape for logistics. The research in the field of autonomous ships[21] [26] is changing the way people think about sea transportation. Another element announcing these changes is the energy issue. The continuous development of propulsion systems and renewable energy sources like offshore wind farms [27] allows to make the claim that operability of intermodal transport can be zero-energy. This is a part of the dynamic development of technologies that allow to control processes in real time, such as for example construction system sensors [19] or safety systems [9].

The development of a dynamic logistic structure creates the need for development and modernization of stationary facilities that are located in places of high transport intensity. Port centres currently in use are developing in line with economic trends [17] towards modern technologies. As logistic nodes, they become important elements of the city structure and affect its daily functioning, therefore the multi-criterial improvement of these facilities is an important factor. The exchange of goods within the city and beyond should be organized in an optimal way so as to reduce the consumption of urban resources, which enable further spatial development. Also subordinate operation of global logistics to mass transport for basic goods.

2 RESEARCH METHOD

To obtain the best possible model result for the characteristics of reality based intermodal transport, an analysis of literature and available technological resources was first performed.

Main aim is to define the possible future shape for a multifunctional facility as an integrator of land and sea transport. The following elements have been analysed in terms of current opportunities and development trends:
- urban overview;
- sea transportation structure;
- land transportation structure;
- logistics facilities structure;
- complementary service support structure.

Compilation and a holistic overview of the global system is necessary to present a model focused on priority requirements. The presented study on the border of architecture and urban planning as well as civil and maritime engineering and logistics is shaped in the adopted design manner defined as Co-Design [16]. Theoretical modelling of a multifunctional building is based on adjusting the system components in such a way that they harmonize with each other. The power of modern technologies to make them purposeful is also inherent in the design approach to implement smart ports design features [4]. They rely on interconnections and automating as a key management element for smart port logistics.

3 INTERMODAL TRANSPORTATION SYSTEM STRUCTURE

Actual logistics relay on multiple modes of transportation. Circulation of passengers and goods can be provided by air, sea or land. Distribution of goods is closely related to port cities agglomerations, where the operations of transferring goods to intermediaries and end users are carried out. The large-scale cargo loads are transported on land in a dispersed form, while on the water surface in a concentrated form. Supply chains are concentrated around large urban centres providing services for various means of transport through various facilities. Distribution centre (DC) can be defined by its location and function in the supply chain. There is a need to create retail network structure models for those types of systems, because of the beneficial effect of significant cost savings under real conditions [13].

The world of autonomous objects and their characteristics is constantly evolving. Currently existing systems require a high involvement of the human factor in management. However, the functional aim is level 5, this is "Full Driving Automation", where the intervention of the driver is not required for the entire travel distance. The presented compendium of current solutions [7] shows that the integration of transport infrastructure on many levels, even in the air, based on automation is inevitable. Let's develop this approach with regard to reloading of goods, where there is a need to optimize the current solutions.

3.1 *Urban overview*

Current trends indicate that logistics centres are the main components of the supply chain. From an urban perspective, container terminals grow to unimaginable sizes. Figure 1 shows a diagram as a sketch of the relationship between transport logistics and the urban structure. Container terminal is present as the interface between the land and the sea structure. The exchange of goods then passes through the logistics centre which concentrates local distribution. Due to the large-scale impact of infrastructure on port cities, it is possible to reduce its scale by optimizing the functional and architectural structure of dedicated facilities. Thus, from an urban perspective, it is possible to shift the burden of container landfills to logistic centres, while port units would be only transfer units.

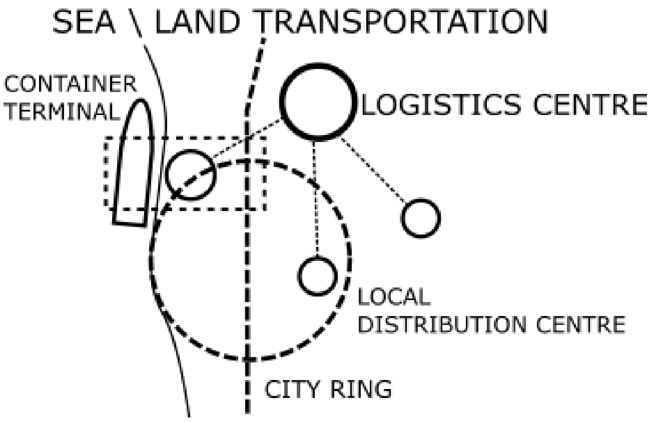

Figure 1. Functional scheme for intermodal logistics supply chain in the city ring structure context.

Calculating routes for land transport is extremely important. Converting distance and time has an effect on operating costs. The presented example of transport planning based on technological possibilities [8] is constantly developing. The multifactorial structure determining the functioning of the logistics system in the city has been demonstrated. With regard to the port city, the key issue will be mass distribution based on intermodal transport.

3.2 *Sea transportation structure*

Apart from the legal aspects, the market drive is focused on implementing intelligent systems as automated as possible. Investigations towards procedures of ship manoeuvres [1] shows that defining standards for present fleet is difficult. It reveals that the unmanned ships should be designed and equipped with multi-directional advanced manoeuvring system.

Perhaps the current trend of creating the largest possible container ships will change direction. There are noticeable trends in creating optimal solutions, such as multi-purpose cargo vessels [15], where the desire to reduce units size and introducing the possibility of their various uses is under consideration. Due to the willingness to use electricity or hydrogen, a system of smaller units with a shorter range will be more efficient. However, this would require an improvement in the reloading of the units themselves. Perhaps a new model of a transport ship would be needed, where modularity would allow the propulsion unit to be switched over without reloading. It would be advantageous from the point of view of optimizing the reloading time and simplifying the reloading process at the container terminal.

Figure 2 presents a scheme for a new sea transportation model in comparison to the traditional one. Starting from a container terminal (A) the new approach is a multi-vessel net of electric modular ships. Reducing the size of the vessel will allow to reach many destinations (B, C, D) much faster than before.

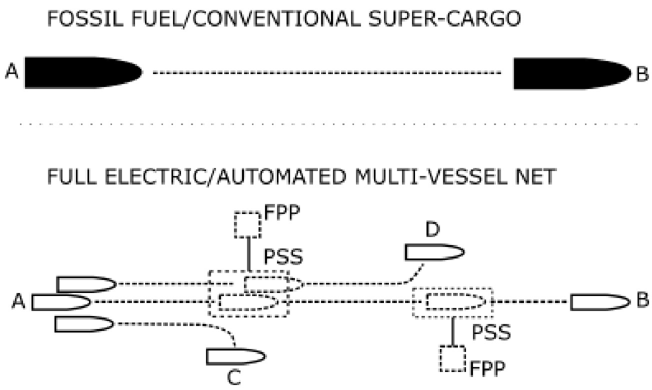

Figure 2. Organizational scheme comparing conventional and automated maritime transport. FPP – Floating Power Plant, PSS – Power Supply Station.

The new model allows for optimal time and distance coverage based on segment stations. Each Power Supply Station (PSS) is connected to and powered by a Floating Power Plant (FPP).

However, when referring to the optimization of the applied solutions, the structure of the water transport system should aim at automation and dynamic adaptation to changing needs within cargo distribution.

As research shows, the key element in the autonomous water transport management system will be wireless connectivity and dynamic information exchange [14]. The presented diagram mega-constellation for global connectivity as a system of dynamic information exchange on the water connects with the world where port centres play the role of managing and supervising this system. The proposed multi-functional solution is another link in this logistic transport supervision system, where the water handling system has to integrate to some extent with land transport management.

The formation of maritime autonomous surface ships (MASS) and the related requirements and procedures takes place on the basis of legal regulations that must keep up with the constantly developing innovative technologies [2]. These technologies will largely determine the shape of the port structure that should be designed to adapt to new opportunities.

3.3 *Land transportation structure*

Contemporary tendencies are directed towards drastic reduction and finally elimination of conventional fossil fuels powered engines. Modern technologies make it possible to productively use only electrically driven means of land transport. Developed technologies related to the development of large-scale production of hydrogen fuel are also considered [3]. Assuming that this is the most environmentally-friendly technology and it allows to provide the right amount of energy at high consumption power demand phase, it will require adaptation of various types of motor vehicles. Moreover, it would be possible to use this technology in mass sea transport. Therefore, it is important to look at all components of transport logistics in a comprehensive manner. The potential of new designed systems allows them to be adapted to each other, which will also translate into a positive ecological effect. Furthermore, a new approach to the design of port facilities is in line with the development of market competitiveness [24] despite not increasing their size.

In order to ensure the compatibility of the implemented solutions and, perhaps, to integrate some elements of the system, so that they enable the fastest possible distribution of goods in a network-centric system of logistic connections. The way land transport will operate in the future is defined as a combined road and railway solution [12]. Striving to the system optimization forces the redefinition of means of transport so that they are compatible with each other. The overriding goal is to make long-distance mass transit smoothly harmonize with individual regional transit. This would mean adapting the dimensions and vehicles to the new realities of the global transport system based on renewable energy.

Inland multimodal transport is defined as a multi-level system of connections. It is possible to distinguish two main modes of communication. Land vehicle system is shown in Figure 3. The diagram shows the logistic structure based on distribution centres (DC). There are two types of transport. The first, mass transport based mainly on rail connections and takes place between distribution centres. And the second, road transport, which at first connects larger distribution centres with local centres (LD). Then the goods are distributed locally, where they will finally reach individual recipients. The structure of land logistics has a strictly defined hierarchy. The highest level is determined by the greatest mass and the greatest distance. Then, in the pursuit of an individual recipient, there is a descent by further levels. At each level, the mean of transport is changed and the scale of the size of the goods is reduced.

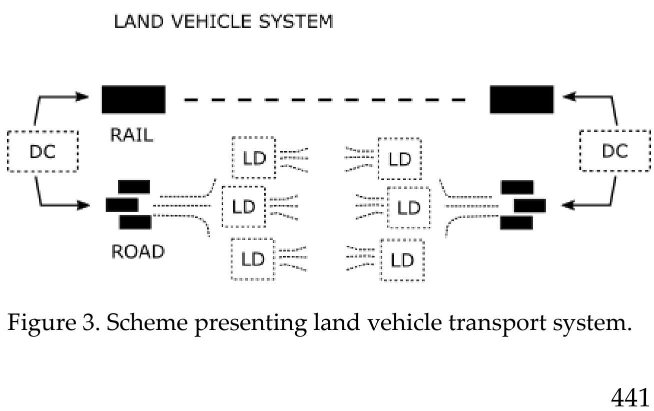

Figure 3. Scheme presenting land vehicle transport system.

3.4 *Logistics facilities structure*

Elements that connect the entire transport network are logistic service facilities. Logistic facilities create a kind of structure that is properly adapted to the system of communication connections. A suitable supply network consists of buildings with a defined range of influence. The following types of objects can be distinguished [8]: Central DC, Regional DC and Local DC.

Figure 4 presents a scheme for distribution facilities system. According to this structure the movement of goods is regulated. Each of these facilities has its own specificity. The multitude of definitions of the logistics centre[18] itself indicates a large diversification of the operation of logistics structures. In addition, the listed features of this type of facilities represent the functional spectrum without which the supply chain could not work.

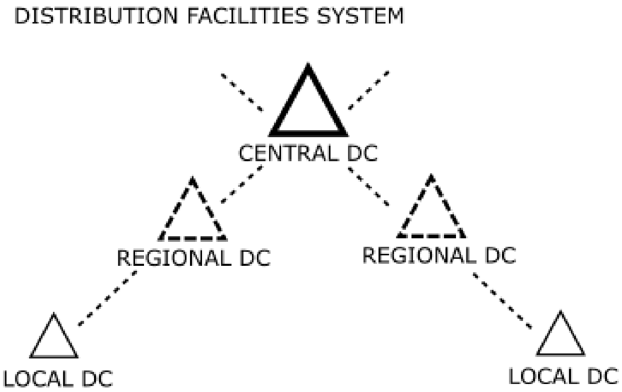

Figure 4. Organizational scheme for land distribution facilities system.

Container terminal is also an element of the land transport system. The development of this type of facilities should take into account a design approach focused on optimization of exploitation, which can be achieved by implementing a multi-criteria approach in the design process [11] with respect to transport structures in terms of the global system impact. From a design perspective, such multi-functional structures will be crucial in order to achieve an ecologically sustainable approach. Organizationally, these types of objects are integrating connectors between land and sea paths.

The development of the logistics structure on land depends on the method of shaping the port structure. Both locally and at longer distances from land. After analysing the development of the various phases for a Spatial Model on Logistics Sites in the Port Hinterland [22], it shows that the greatest pressure of accumulation of goods is on the edges of land and sea. This structure then becomes even more densified. This process should be revised. Perhaps port development should aim at minimizing the size in favour of optimizing transit.

Thus, connexion with a container terminal in the structure described above may be crucial for the organization of the distribution process, but it will mainly depend on the way in which it operates. Two types of relations within the land distribution facilities structure are presented in Figure 5. First a) is a standard relation with the container terminal and logistics facilities. Second b) defines the container terminal as a Central Distribution Centre. There are significant differences between the presented diagrams, which affect the way of operation. Taking into account the structure of operation and the integration of all transport systems involved in this structure, it will entail appropriate design requirements for a dedicated port facility.

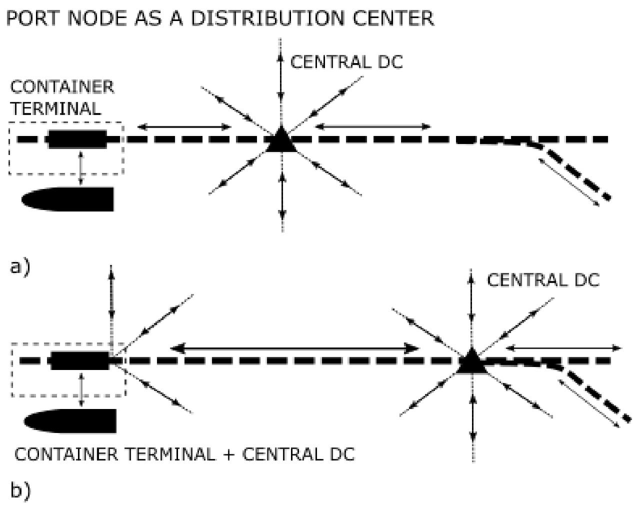

Figure 5. Relations within the land distribution facilities structure a) connection between container terminal and central Distribution Centre, b) container terminal with central DC within the land distribution structure.

4 MULTIFUNCTIONAL SYSTEM STRUCTURE FOR LOGISTICS FACILITY

Designing the structure, two-way traffic movement should be taken into account, where both the receipt and the release of goods should take place in parallel. The generally accepted design solution for container terminals seems to be appropriate for the quantitative optimization of the transport of goods. However, in the future, transport should be focused on qualitative optimization. Logistics units should be designed for the fastest possible shipment of goods and distribution of them. Where also the size of the facility should be optimized in order to save land, the layout of the loading cranes together with the IT system to increase parallel operations. As different container terminal systems have different parameters [6] in terms of environmental impact assessment, the building in question, which provides this function, should be focused on optimization in the direction of minimizing energy consumption.

The guidelines for the design of this facility are the reduction of the container path between the means of transport, which in the process of full automation will allow for more detailed supervision over the operation and ensure greater safety. In addition, the intensity of the containers stored on site is reduced, as the terminal will serve better in distribution nor collecting. This may be a remedy for the reported problems [5] of container terminals.

4.1 *Functional programme*

As defined [23], the coordination of interests requires a coordination centre, i.e. an integrator, which in the context of globalization becomes virtual and acquires the features of a cyber-physical system, the role of which may be played by transport and logistics platforms.

To determine this specialised building structure at first is defined the proper functional program with defined basic purposes ensuring the operation of all specified elements of the transport system. The functional program is presented in Table 1.

Table 1. Building functional program.

Symbol	Description	Connections
S	ship landing place	A, M, V
R1	railway depot	V, A, M
R2	road depot	V, A, M
A	transhipment area	O, M, S, R1, R2
M	automated multi-lift matrix	O, A, S, R1, R2
O	offices	A, M, V
V	autonomous vessel service	S, R1, R2

The logistics structure from the mathematical point of view can be presented by a graph (Figure 6.) within the entire building multicriteria model. Implementation of reaction connections between all elements complete the structure of overall model. The structure form with a hierarchical layout containing:
- Lifecycle phases (p1, p2, …),
- Basic Criteria (b1, b2, …),
- Multifunctional Building System (F, C, T, e1, g1, …),
- Stakeholders group (s1, s2, …).

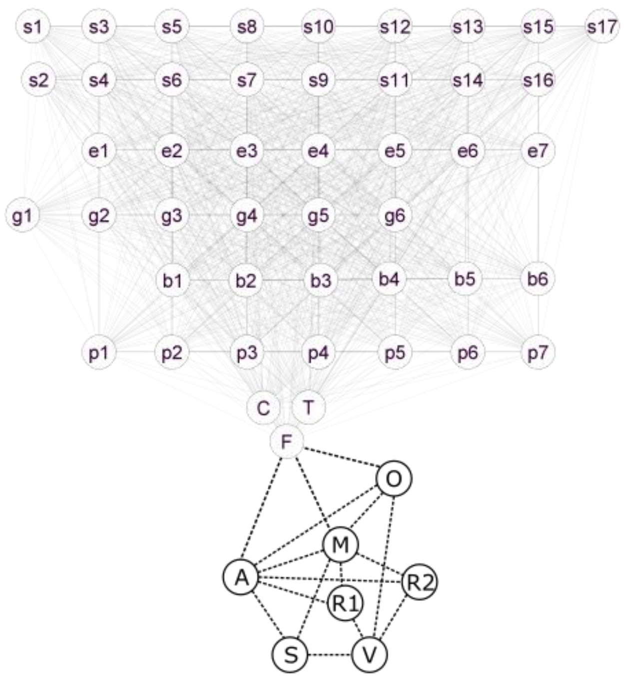

Figure 6. Building multicriteria model scheme with logistics facility functional structure.

The actual multifunctional building design process expands its scope to reach every possible impact it brings. Due to the above specified basic criteria the design process needs to consider the whole building lifecycle. It is necessary to predict what will happen with the system elements when they reach their timeline, what is possible to do with them, how to replace them. Application of the lifecycle enables also optimization at the level of building design, structure realization and building operation. Presented Lifecycle Phases are:
- Initial Work (p1),
- Concept (p2),
- Project (p3),
- Construction (p4),
- Exploitation (p5),
- Waste (p6),
- Recycling (p7). [25]

Global tendencies of building development throughout analysing contemporary goals for urban areas must meet the most objective criteria. Well known criteria like aesthetics and functionality are supported by specified durability parameters. It is crucial for multifunctional building to predict the influence on natural environment, to guarantee the safety of people, to plan effectiveness of the investment and give a possibility for easy functional adaptation to the dynamically changing needs of users. Below are defined Basic Criteria:
- Aesthetics (b1),
- Functionality (b2),
- Natural Environment Protection (b3),
- System Safety (b4),
- System Effectiveness (b5),
- Functional Flexibility (b6). [10]

The main core of the Multifunctional Building System (MBS) is the Internal Functional System (I). These elements are defined by the functional programme, the building construction and applied technologies. It is a structure defined by the main building characteristics:
- Functional System (F),
- Construction System (C),
- Technology System (T).

External Functional System (E) are all characteristics of the city context environment for the defined building structure. They have a connection or direct influence on the system core, the Internal Functional System (I). In the system structure this subsystem is placed between the internal part and the global environment. Included system components are:
- Weather Conditions System (e1),
- Urban Greenery System (e2),
- Urban Functional System (e3),
- Social Network System (e4),
- Technical Infrastructure System (e5),
- City Logistics System (e6),
- City Transportation System (e7).

Global Environment System (G) is defined with subsystems in a wide range. These elements define general principals regarding main causes and the main effects of the structure formation. Presented subsystems are:
- Natural Environment System (g1),
- Social System (g2),
- Legal System (g3),
- Economic System (g4),
- Geographic System (g5),
- Land Management System (g6).

Multifunctional building design involves multiple stakeholders within the process. They participate in the design and assessment process, when the building's essential function and infrastructure are defined [20]. In multifunctional building design process following Stakeholders Group (S) is involved:

- consortium of the construction investment (s1),
- architect (s2),
- project manager (s3),
- construction industries engineers (s4),
- safety engineer (s5),
- contractors of construction work (s6).
- material suppliers (s7),
- technology providers (s8),
- recycling company (s9),
- local government (s10),
- local community (s11),
- public services (s12),
- facility staff (s13),
- building users (s14),
- property administrator (s15),
- real estate market regulator (s16),
- insurance company (s17). [11]

Nodes - present physical functional spaces and edges - present dynamic paths of decisional and functional flow of information. In general this network presents the whole building structure with detailing the two way connections for land and sea logistics interference. Parameter M – automated multi-lift matrix was proposed in the functional structure F, which is an innovative element, however, this would not be possible to provide without the entire architectural structure. The lifts are in a grid system and move in many ways and in different directions. The multi-lift matrix is a critical element that optimizes the logistics handling performance. According to the diagram, it is in central position and its task is to connect all means of transport.

4.2 *Terminal layout and design context*

Definition of functional program and analysing the functional connections enables creation of the structure layout and after that presenting model in the city context. Port logistics facility functional scheme is presented in Figure 7. Large rectangle drawn with dotted line shows the structure suspended above the transhipment area. An automated lifting mechanism was suspended from it, while the space above was used for service and offices. In addition, in order to meet more stringent ecological requirements, the roof of the facility can be equipped with a photovoltaic installation that can support the operation as well as magnetic berthing. The presented system enables fast intermodal reloading. The handling of two quays enables reloading from a large facility to two smaller ones at the same time. It may be an important feature for this type of facilities, due to the possibility of using inland waterways.

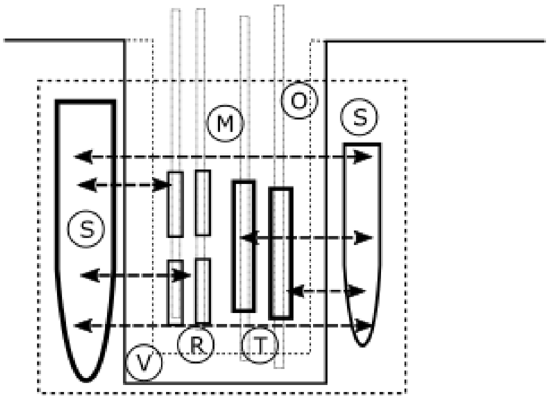

Figure 7. Port logistics facility functional scheme.

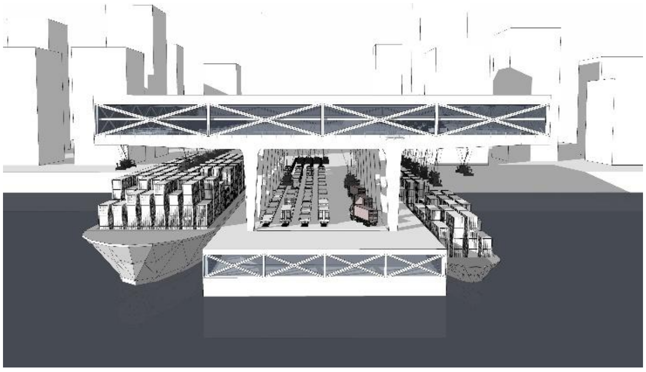

Figure 8. Port logistics facility. View from the open sea.

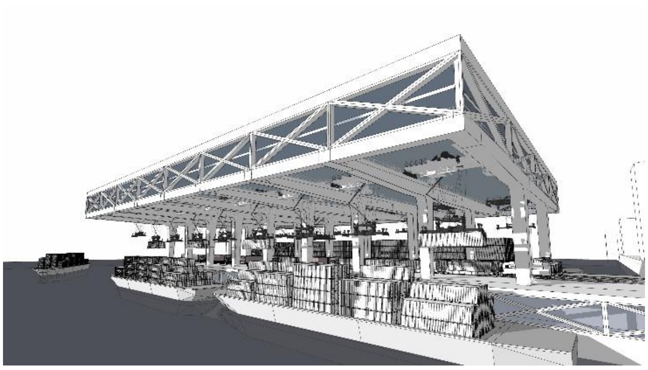

Figure 9. Port logistics facility. View from the waterfront.

Presented multifunctional system for logistics facility has a model and conceptual structure. Modern IT, technological and mechanical possibilities make it possible to create this type of systems in reality. In order to meet the needs of automated means of transport, the presented model introduces automated handling to a new level. This will require a change in the approach to cargo travel planning. Where, during shipping, a given module is located in the structure of individual means of transport.

With regard to architectural aesthetics, industrial facilities also determine the quality of urban space. Perhaps the presented conception is a proposal for intensively developed urban areas, where it is necessary to limit logistics container space, and at the same time create an aesthetic representational port city landscape.

5 CONCLUSIONS

The presented results refer to the optimization of the design of multi-functional structures for servicing port logistics centres. The results of the research presented include a new look at the elements of the current logistic structures. The main results of the assumptions indicate:

– ensuring, in the layout of the container terminal facility, the possibility of handling goods reloading adapted to autonomous maritime and land facilities;
– transforming a container terminal into a multi-level logistics centre closely connected with the hierarchical arrangement of land distribution facilities;
– enabling the improvement of logistics operations in the local context by providing the service of autonomous means of local transport;
– matching the berth and size of maritime transport vessels as an integrated structure with cargo handling devices;
– optimizing the layout of land objects in terms of the hierarchy of distribution of goods;
– expansion of the scope of activities of a container terminal with distribution centre possibilities will reduce the number of central distribution centres within the land facilities system;
– optimization for basic transhipment from ship to rail will reduce mass road transport, which role will be limited to local distribution only;
– reducing size of container terminal will save a lot of valuable coastal space for the benefit of urban centres.

Currently, each dedicated specialistic logistic facility develops its own logistics infrastructure. It would be possible to expand the activities of multi-functional structures, striving to develop intermodal transport in these areas.

Despite the fact that this type of facility introduces many improvements in the operation of the direct location supply chain, it imposes restrictions on the size of the ships handled.

Looking from the architectural point of view the port cities with their port facilities of the future can be designed in a compact and optimized manner, so that they do not interfere with the urban space while striving to optimize efficiency.

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