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An Expert Knowledge-Based System to Evaluate the Efficiency of Dry Construction Methods

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Abstract: The issues that the construction sector currently faces with regard to productivity and efficiency are well acknowledged. In the construction industry, there is plenty of space for efficiency to improve, with an increasing number of new tools and methods coming out. One of the solutions to increase efficiency is the application of modern methods of construction. The modern methods of construction, especially dry construction techniques, are developing so that there is a larger volume of high-quality production with a shorter time for procurement. Not only in the construction of skeletons but also in the finishing works, it is a huge advantage if there are implemented techniques that eliminate traditional wet construction works and thus shorten the construction time. On the other hand, however, the question of efficiency in relation to their costs is raised. Based on theoretical and empirical research, the aim of this study is to demonstrate the potential of modern dry construction systems and solutions for finishing works, especially in relation to the construction time and construction cost. For this purpose, an expert knowledge system, named the complex COMBINATOR, was developed. Through a set of simulations with the help of the COMBINATOR, the effects of different combinations of dry construction systems and techniques (DCSTs) and traditional wet construction systems and techniques (WCSTs) on the time and cost of finishing construction works were measured. Based on the results of simulations carried out through the complex COMBINATOR with an inference engine that enabled these simulations, the potential of dry construction techniques for the implementation of finishing works in the construction of residential buildings was demonstrated. Without simulating the effects of the individual technological models for finishing construction works in relation to two of the most important parameters of construction projects, namely time and cost, it would not be possible to obtain the resulting parameters for different combinations of DCSTs and WCSTs from the study presented. Therein lies the huge importance of the presented knowledge system for deciding on the benefits of DCSTs.

Keywords: knowledge system; knowledge base; construction; dry construction; construction time; construction cost

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Citation: Kozlovska, M.; Duris, A.; Strukova, Z.; Tazikova, A. An Expert Knowledge-Based System to Evaluate the Efficiency of Dry Construction Methods. *Appl. Sci.* **2023**, *13*, 11741. https://doi.org/10.3390/app132111741

Academic Editors: Paulo Santos and Cesare Oliviero Rossi

Received: 25 September 2023
Revised: 16 October 2023
Accepted: 25 October 2023
Published: 26 October 2023

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1. Introduction

The current construction industry is largely characterized by an increase in pressure on the speed of the construction process and a greater emphasis on the environmental impact during the construction and use of buildings. The construction industry makes efforts to improve these parameters with innovative solutions. One of the possible solutions is the use of modern methods of construction (MMC), which improve the construction process from a material, structural, and technological point of view. The MMC's potential for securing such goals is described in a range of resources. The authors of various studies [1–5] claim that MMC are characterized by increased productivity, better quality, reduced construction time, lower overall construction costs, increased protection of health and safety at work, less construction waste and environmental emissions, and a reduced consumption of energy and water. According to some authors [6], MMC represent technologies that provide

efficient procedures for the preparation and implementation of construction, the result of which is larger production that is of higher quality and a shorter time of procurement. The MMC are mainly prefabricated structures, which are characterized by production in factories followed by dry construction work/techniques directly on the construction site.

Prefabricated structures are generally perceived as environmentally friendly structures and are glorified in a global sense. However, in many countries, the rate of promotion and application of prefabrication is still slow and constantly compared to traditional on-site construction methods characterized by wet construction works [7,8]. Prefabrication transfers part of the on-site work to factories and creates the need to coordinate suppliers and subcontractors of prefabricated elements so that these elements are on time at the right place of installation [9]. Off-site manufacturing of prefabricated structural elements and systems for dry construction is a modern construction method that brings various benefits to stakeholders, not only in terms of environmental sustainability [10]. The overuse of natural resources and the lack of a workforce in the construction sector encourage the development of prefabrication. It is one of the reasons for the more extensive application of prefabricated systems and techniques, which optimize resources and at the same time shorten construction times [11–13]. The development of prefabricated structures has become one of the primary solutions to the transformation of the traditional construction industry worldwide. Based on the research results of Han, Y.H. et al. [14], governments, developers, and consumers make policy recommendations for the development of prefabricated structures. Similarly, research by Zhou et al. [15] concluded that prefabricated structures can reduce carbon emissions by approximately 86 kg per square meter compared to traditional structures. Thus, modular prefabricated structures with an improved composition could overcome the disadvantages of current construction practices with high carbon emissions [16–18].

Modular building systems are still in the development phase of their popularity in this industry, while new structural designs of dry construction (drywall partitions, dry screeds, dry linings, and suspended ceilings) are also appearing. Compared to the traditional wet construction of partitions, floors, walls, and ceiling plasters, dry construction techniques potentially improve the properties of these structures, such as material, static, fireproof, acoustic, seismic resistance, etc. [19–25].

The current construction market offers a large number of variants and possibilities for the implementation of wet or dry construction, from the foundation of buildings through skeleton construction to finishing works. Some clients are inclined towards traditional methods, also known as wet construction; others prefer dry construction systems and techniques, or the possibility of combining wet and dry techniques and construction systems. In addition to the above-mentioned pressures on the environmental aspects of the construction industry, the industry is moving towards efficient construction in terms of construction costs and construction time. Therefore, when designing and assessing a project, clients emphasize the amount of necessary funds and the time or date when they will be able to hand over the building for use. Designers are therefore looking for suitable construction systems and techniques to meet the demands of investors. As part of the study, which is the subject of the article, a knowledge system of time and cost parameters of selected dry and wet construction systems and techniques for finishing works in buildings (partitions, ceilings, wall finishes, and floors) was developed. This knowledge arrangement enables both the designer and the client to model and compare the effects of different variants of dry construction solutions (including a comparison with traditional techniques in relation to costs and time of their implementation) even in the phase of searching for a suitable structural solution for a building.

Some researchers have dealt with knowledge management factors to make quality strategic decisions. Knowledge management systems improve the quality of decision-making [26]. When analyzing decision-making, it is typically assumed that the decision-maker has difficulty choosing between several possibilities. In order to make decisions that are logical and justifiable, the decision-maker must, in theory, have some understanding of

the phenomenon [27]. Knowledge-based systems are expert systems that model information and transform it into knowledge. They analyze various types and volumes of data to address specific issues in particular fields [28]. They work on the principle that the user provides various facts and receives expert advice as a response from the system. If the user is an expert, the system serves as a support that can help to more effectively find a solution to the problem [29]. When creating and implementing information and knowledge systems, which must be able to respond to new trends in the field of knowledge sharing, the content of the knowledge base is one of the most important elements on which the success of the knowledge system is based [30]. Knowledge is understood as interconnected structures of related knowledge. Knowledge of something means its representation in the form of a cognitive model, including the ability to perform various cognitive operations with it [31]. We understand expert systems as a special type of knowledge system, which is characterized by the use of knowledge obtained exclusively from an expert and some other characteristics, such as a specially oriented explanatory mechanism. Recently, there has been a blurring of the differences between these terms, or the originally conceived exclusively expert systems are already conceived as more general knowledge systems [32].

Based on theoretical and empirical research, the aim of this study is to demonstrate the potential of modern dry construction systems and solutions for finishing works, especially from the time and cost points of view. For this purpose, an expert knowledge system was developed. The expert knowledge system is based on a detailed analysis of the technological parameters of both dry and wet systems and techniques for finishing works in order to simulate the effects of these systems and techniques on the construction cost and construction time of a project.

Similar to us, for example, the possibilities of the dry construction of partitions were also the subject of studies by researchers who presented a method of responsible selection of the optimal composition of cladding of wooden structures with plasterboards. Wooden structures pollute the environment significantly less than structures made of bricks, glass, or concrete. These dry-build structures include walls that use composite materials based on gypsum and paperboard, and materials based on gypsum and cellulose fibers for the interior surfaces of the walls [33,34].

Optimization problems arise in many real-life applications, such as scheduling [35] and resource allocation [36,37]. Optimization problems focus on the best possible decision from a set of many options; in our case, it is first about the choice of a wet or dry construction method, followed by the selection of a specific system or technique for finishing works. While different systems cover different construction materials. Such decisions are often taken with the aim of maximizing profit, minimizing costs, and the implementation time, which are subject to economic needs such as the production capacity or availability of resources, but also with the aim of minimizing the impact of construction on the environment. Knowledge systems help solve optimization problems [38].

2. Materials and Method

A knowledge system is an expert system that enables solving problems based on the knowledge base through productive procedures [39]. The core of the knowledge system consists of three components, which are the knowledge base, the inference engine, and the working memory. The model of the above-introduced knowledge system is presented in Figure 1. In the knowledge base, knowledge is understood as a variable system with mutual interactions of facts, relationships, experiences, thoughts, meanings, etc. The inference engine is a program module that selects the knowledge that needs to be interpreted from the knowledge base. Working memory is a temporary working database. All data that the system obtains from outside or derives from other data based on the knowledge in the knowledge base are maintained in it.

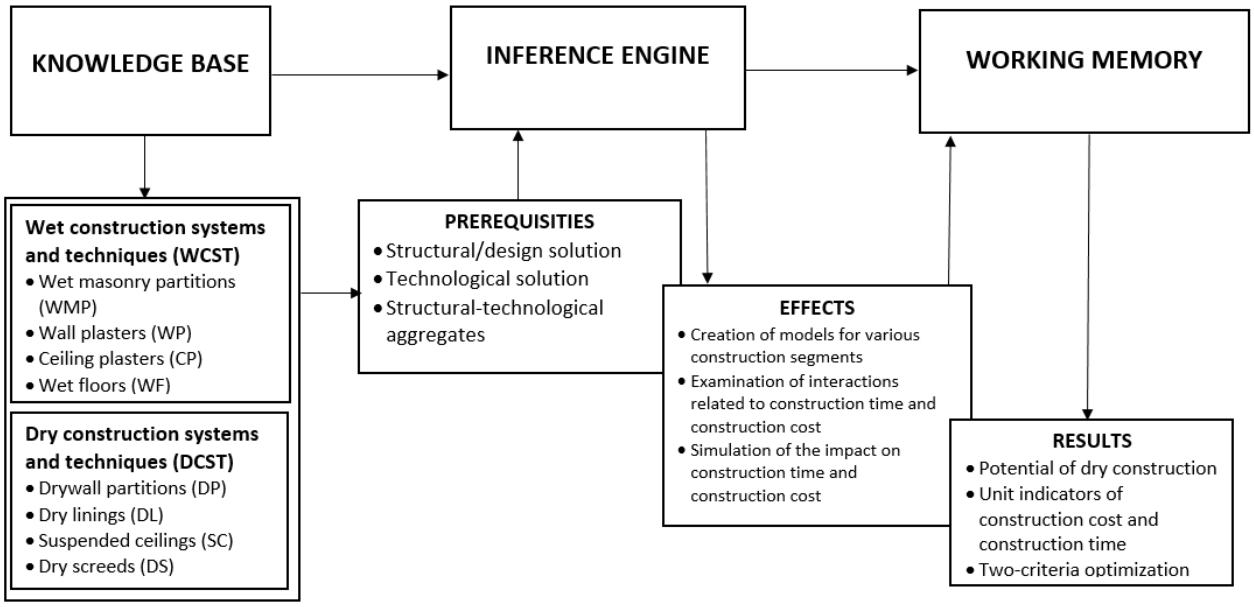


Figure 1. Model of the knowledge system for the examination of dry construction systems and techniques in the context of the entire design solution of the building.

The primary step of our investigation was to analyze the parameters of various systems and techniques for finishing works. The analysis, which also included a survey of supporting planning tools provided by the manufacturers of DCSTs, has focused on the following aspects: construction material used, system technology, time characteristics, cost characteristics, and user requirements. As part of further specification and synthesis of knowledge from the previous analysis, knowledge about DCSTs and WCSTs was organized in the respective knowledge bases. Subsequent modeling included the design of a knowledge system and the creation of technological models, i.e., combinations of DCSTs and WCSTs for the construction of partitions, wall and ceiling finishes, and floors in buildings. The developed knowledge system and technological models were the basis for simulating the effects of individual construction systems and techniques in the field of construction costs and construction time. The scientific conclusions from our study were induced on the basis of a wider set of simulations of finishing works on cases of construction projects from different segments of residential buildings.

The spreadsheet software MS Office Excel 2019 with macros for the automated selection of suitable dry or conventional construction systems and techniques for finishing works was applied to create a knowledge base and serve as an inference engine. The structure of the knowledge base includes basic data on dry or traditional construction systems and techniques and basic parameters such as construction cost, labor intensity, and weight. These basic data allow the knowledge system to simulate the effects of applying different types and combinations of dry construction systems and techniques (DCSTs) on construction time and construction costs. Based on the results of the simulations, the client can decide to adopt systems and techniques that clearly ensure a reduction in construction time. A balance of this time benefit with a possible higher cost is questionable. The working memory module can answer such questions. The module is able to process the effects and combinations of different models of systems and techniques for finishing works with regards to the construction time and cost indicators. To develop the knowledge base, the data on systems and techniques for finishing works were obtained from existing knowledge systems.

Most types of construction systems and techniques for finishing works with relevant data were taken from the construction software CENKROS 4 2021/II, which contains CENEKON price list databases. The databases include the systems and techniques for the finishing works being offered by some selected manufacturers. Data on systems and techniques that were not part of these databases were collected directly from the technical

documents of manufacturers. The following available knowledge systems were used: Farmacell Selector—Fermacena, Rigips tool, Rigips Selector. These knowledge systems are in the form of freely available online tools. They are used not only by designers and installers, but also by clients, who can use it to calculate the final amount of consumption for the chosen structure and find out the exact amount of material and its price that is needed for the designed construction project.

2.1. The Construction Software CENKROS 4 and Available Knowledge Systems of Dry Construction Systems and Techniques

The CENEKON price list databases, which are part of the construction software CENKROS 4, were used to develop a knowledge base in terms of cost parameters. The construction software CENKROS 4 is generally the most widely used tool for estimating and managing construction production in Slovakia. Export reports with cost parameters (material costs, labor costs, overheads, and profit) of all dry and traditional construction systems and techniques of finishing works were generated from the software. In addition to the cost parameters, each item in the base contains the following information: item code, unit labor intensity, and weight.

Currently, manufacturers of some dry construction systems support various structural and technical solutions with their own modern information tools. Through these tools, the user has the opportunity to influence the design of the system and obtain information about the required type and quantity of products and components, and possibly also about their price.

Rigips is one of the most important developers of dry construction systems and techniques. A freely available tool (available on the Rigips website and independent of an internet connection when downloaded)—the Rigips tool—and an internet application—the Rigips selector—are used to design and calculate the systems offered by this company. Designing dry construction systems and technologies through the Rigips tool is possible for different finishing works (drywall partitions, dry linings, suspended ceilings, and dry screeds) individually. It is not possible to create combinations and sets of selected finishing works. In addition to selecting a solution based on the required structural and technical properties, the online version of the information tool—Rigips selector—has the function of processing calculations for Rigips system structures and enabling the insertion of the selected structure into the project in the drawing/modeling software (library of 3D structures).

The online tool by the Fermacell company, known as Fermacena, works in a similar way. The company offers mainly gypsum fiber and cement fiber products for finishing works based on dry construction systems. It allows information to be input about the buildings and deals with all structural layers of the proposed systems. After entering the input parameters (fire protection, acoustic, construction thickness, sort, and type of insulation), the knowledge system generates a structural solution for the wall, floor, or ceiling system with material and technical information about the built-in products. Based on the indicative material consumption, the cost of the solution is also determined.

2.2. The Knowledge Base of Dry Construction Systems and Techniques (DCSTs) and Wet Construction Systems and Techniques (WCSTs)

The knowledge base, incorporating data and information on both the DCSTs and WCSTs of finishing works, was designed in the composition, which is presented in Table 1. The base includes the systems and techniques as follows: (i) wet masonry partitions (WMPs), (ii) drywall partitions (DPs), (iii) ceiling plasters (CPs), (iv) suspended ceilings (SCs), (v) wall plasters (WP), (vi) dry linings (DLs), (vii) wet floors (WFs), and (viii) dry screeds (DSs).

Table 1. The composition of the data in the knowledge base.

Data Group	Data
General data on dry and wet construction systems and techniques	Type of system or technique; Name (description) of the system or technique; System or technique number of the 3D library classified by the manufacturer; Code of the system or technique in CENEKON price list databases.
Basic parameters	Unit labor intensity [Nh/u.m.]; Length of technological break; Unit price (including costs, overheads, and profit); Unit weight of the system/structure.

Nh: norm hour; u.m.: unit of measure.

As part of the development of the knowledge base of DCSTs, a total of 620 dry construction systems and techniques were analyzed in the following breakdown: 315 drywall partition systems and techniques, 140 suspended ceiling systems and techniques, 103 dry lining systems and techniques, and 62 dry screed systems and techniques. Their resulting classification in the knowledge base according to construction types (drywall partition, suspended ceiling, dry lining, dry screed) is prepared in an MS Office Excel table environment. Summarizing the knowledge base included a survey of designing and selecting tools and other supporting tools (CENKROS 4 software, online tools of dry systems and techniques manufacturers), from which data on dry construction systems and techniques was taken.

A selected part of the knowledge base on drywall partitions (DPs) is presented in Table 2. The entire knowledge base for other types of construction within dry construction systems and techniques (DCSTs), i.e., suspended ceilings (SCs), dry linings (DLs), and dry screeds (DSs), was processed in an identical structure. Technological break (TB) is the number of days required for the maturation of the material/structure after wet construction works.

Table 2. A selected part of the knowledge base on drywall partitions (DPs).

General Data				Basic Parameters			
Type of DCST	**Description**	**ID Number (3D)**	**CENKROS 4 Code**	**Labor Intensity [Nh/m^2]**	**TB [day]**	**Cost [EUR/m^2]**	**Weight [t/m^2]**
DPs	Plasterboard partition wall th. 75 mm one-side sheathed with RB 12.5 mm boards, CW 50	3.40.01a	763115100	0.915	1	25.27	0.022
DPs	Plasterboard partition wall th. 75 mm one-side sheathed with RF 12.5 mm boards, CW 50	3.40.01b	763115101	0.919	1	26.45	0.025
DPs	Plasterboard partition wall th. 75 mm one-side sheathed with RBI 12.5 mm boards, CW 50	3.40.01c	763115102	0.923	1	28.13	0.022
DPs	Plasterboard partition wall th. 75 mm one-side sheathed with RFI 12.5 mm boards, CW 50	3.40.01b(f)	763115103	0.923	1	29.37	0.031
DPs	Plasterboard partition wall th. 75 mm one-side sheathed with RB 12.5 mm boards including thermal insulation, CW 50	3.40.01b(a)	763115111	0.918	1	28.00	0.023
DPs	Plasterboard partition wall th. 100 mm one-side sheathed with RB 12.5 mm boards including thermal insulation, CW 75	3.40.02(a)	763115112	0.919	1	30.15	0.023
DPs	Plasterboard partition wall th. 125 mm one-side sheathed with RB 12.5 mm boards including thermal insulation, CW 100	3.40.03(a)	763115113	0.921	1	32.04	0.024
DPs	Plasterboard partition wall th. 100 mm one-side sheathed with RB 12.5 mm boards, CW 75	3.40.02(b)	763115120	0.915	1	26.08	0.022
DPs	Plasterboard partition wall th. 100 mm one-side sheathed with RF12.5 mm boards, CW 75	3.40.02(c)	763115121	0.919	1	27.25	0.025

DCSTs: Dry construction systems and techniques; DPs: Drywall partitions; TB: Technological break.

The knowledge base of traditional wet construction systems and techniques was also prepared in the MS Office Excel environment. It covers all traditional construction systems and techniques for finishing construction works that were found in the CENEKON price list database, which is the essential database of the CENKROS 4 software. Thus, the knowledge base of traditional wet construction systems and techniques (WCSTs) includes 798 systems and techniques, which are also classified by type of construction: 107 techniques of wet masonry partitions (WMPs), 248 techniques of ceiling plasters (CPs), 236 techniques of wall plasters (WPs), and 207 techniques of wet floors (WFs).

A selected part of the knowledge base on wet masonry partitions (WMPs) is presented in Table 3. In an identical structure, the whole knowledge base on other types of WCSTs, i.e., ceiling plasters (CPs), wall plasters (WPs), and wet floors (WFs), was prepared. Unlike dry construction systems and techniques, traditional construction systems and techniques do not have 3D libraries for modeling and designing software. Therefore, the ID data for 3D are missing in the knowledge base.

Table 3. A selected part of the knowledge base on wet masonry partitions (WMPs).

General Data				Basic Parameters			
Type of WCST	**Description**	**ID Number (3D)**	**CENKROS 4 Code**	**Labor Intensity [Nh/m^2]**	**TB [day]**	**Cost [EUR/m^2]**	**Weight [t/m^2]**
WMPs	Partitions made of fired bricks POROTHERM 8 P 8, on mortar POROTHERM MM 50 (80 × 500 × 238)	-	342242020	0.509	3	21.386	0.08465
WMPs	Partitions made of fired bricks POROTHERM 11.5 P 8, on mortar POROTHERM MM 50 (115 × 500 × 238)	-	342242021	0.552	3	24.513	0.10942
WMPs	Partitions made of fired bricks POROTHERM 14 P 8, on mortar POROTHERM MM 50 (140 × 500 × 238)	-	342242022	0.616	3	28.095	0.14810
WMPs	Partitions made of fired bricks POROTHERM 17.5 P 12, on mortar POROTHERM MM 50 (175 × 375 × 238)	-	342242023	0.699	3	34.457	0.17541
WMPs	Partitions made of fired bricks POROTHERM 8 Profi P 8, on POROTHERM Profi mortar (80 × 500 × 249)	-	342242030	0.449	3	21.345	0.07171
WMPs	Partitions made of fired bricks POROTHERM 11.5 Profi P 8, on POROTHERM Profi mortar (115 × 500 × 249)	-	342242031	0.483	3	25.768	0.09683
WMPs	Partitions made of fired bricks POROTHERM 14 Profi P 8, on POROTHERM Profi mortar (140 × 500 × 249)	-	342242032	0.504	3	29.123	0.10626
WMPs	Partitions made of fired bricks POROTHERM 17.5 Profi P 12, on POROTHERM Profi mortar (175 × 375 × 249)	-	342242033	0.529	3	37.699	0.14075

WCSTs: Wet construction systems and techniques; WMPs: Wet masonry partitions; TB: Technological break.

2.3. The Development of the Knowledge System of Systems and Technologies for Finishing Construction Works

In addition to the knowledge base, the inference engine is an inseparable part of the knowledge system and its core. It also needs to be programmed with macros. It works as a program module that selects the knowledge needed to be interpreted from the knowledge base. In our knowledge system, which is the subject of this article, the effects of using different types and combinations of DCSTs on the construction time and construction cost of finishing works and, thus, on the overall time and cost of a project can be simulated. A client or designer can therefore quickly decide on acceptance or non-acceptance of selected systems and techniques. The inference engine evaluates them in terms of construction time and construction cost parameters; that is, in terms of the time required to implement the work in norm hours [Nh] and the length of technological breaks in terms of cost and structural weight.

In our case, the unit combinator was initially chosen. It is a type of inference engine for the simple simulation of the effects of unit construction time and construction cost parameters of finishing construction works on the overall construction project time and cost. Based on the selected time and cost parameters, it can choose suitable systems or techniques for the construction of partitions, plasters, ceilings, and floors using either wet or dry techniques and their mutual combinations. After selecting any of the systems and techniques from those found in the knowledge base, the tool automatically displays the basic unit parameters of the construction work, i.e., costs [EUR/m^2], labor intensity [Nh/m^2], and structural weight [t/m^2]. The unit combinator is illustrated in Figure 2.

System or technique		Combinations of DCST and WCST			DELETE
Wet	**Dry**	Type of construction	EUR/m^2	Nh/m^2	t/m^2
WMP	DP	Plasterboard partition wall Rigips 100 mm thick, one-side sheathed with RFI 12.5 mm boards, CW 75	30.172	0.923	0.023
CP	SC	Plasterboard suspended ceiling KNAUF D116, suspension structure profile UA, mounting profile CD, GK BI boards 12.5 mm thick	31.185	0.958	0.014
WP	DL	Interior gypsum wall plaster RIGIPS Rimano UNI 20mm thick	15.19	0.429	0.028
WF	DS	Anhydrite self-leveling cast screed BAUMIT Alpha 2000, class CA-C2 O-F5, 30 mm thick	12.943	0.203	0.066
Total			**89.49**	**2.51**	**0.131**

Figure 2. The unit combinator. DCSTs: Dry construction systems and techniques; WCSTs: Wet construction systems and techniques; WMP: Wet masonry partition; DP: Drywall partition; CP: Ceiling plaster; SC: Suspended ceiling; WP: Wall plaster; DL: Dry lining; WF: Wet floor; DS: Dry screed; Nhs: Norm hours.

However, the unit combinator as an inference engine has worked only with basic parameters (costs, labor, and weight) and has not considered the duration of technological breaks after wet construction works, which are essential to consider for proving the potential of dry construction. Therefore, the unit combinator was expanded with technological models that depend on the sequence of construction works and thus include even a technological break in the case of wet construction work. Three basic technological models were created in the basic classification of combinations:

- M1—model consisting only of wet construction systems and techniques;
- M2—model consisting only of dry construction systems and techniques;
- M3—model consisting of various combinations of dry and wet finishing works.

The order and sequence of construction works in the implementation depends on the choice of systems or techniques of partitions, plasters, floors, and ceilings. The clear sequence and order of works—P_W—is the model M1, a combination of only wet works, as well as P_D in the model M2—a combination of only dry works. With combinations of dry and wet finishing works, there is a change in the sequence of works included in construction. Fourteen different combinations P_1–P_{14} are possible. First, all wet finishing works are carried out, and then, after the end of the recommended technological breaks, dry finishing works are implemented. Technological models for finishing works are presented in Table 4.

Table 4. The technological models of finishing works.

Model	Combinations of Finishing Works Systems and Techniques				Sequence of Works in Implementation	
	Partitions	Ceilings	Plasters (Wall Finishes)	Floors		
M1	WMP	CP	WP	WF	P_W	WMP-TB-CP-TB-WP-TB-WF-TB
M2	DP	SC	DL	DS	P_D	DP-TB-DL-TB-SC-TB-DS-TB
M3	WMP	CP	WP	DS	P_1	WMP-TB-CP-TB-WP-TB-DS-TB
	WMP	CP	DL	WF	P_2	WMP-TB-CP-TB-WF-TB-DL-TB
	WMP	SC	WP	WF	P_3	WMP-TB-WP-TB-WF-TB-SC-TB
	DP	CP	WP	WF	P_4	CP-TB-WP-TB-WF-TB-DP-TB
	WMP	CP	DL	DS	P_5	WMP-TB-CP-TB-DL-TB-DS-TB
	WMP	SC	WP	DS	P_6	WMP-TB-WP-TB-SC-TB-DS-TB
	DP	CP	WP	DS	P_7	CP-TB-WP-TB-DP-TB-DS-TB
	WMP	SC	DL	WF	P_8	WMP-TB-WF-TB-DL-TB-SC-TB
	DP	SC	WP	WF	P_9	WP-TB-WF-TB-DP-TB-SC-TB
	DP	CP	DL	WF	P_{10}	CP-TB-WF-TB-DP-TB-DL-TB
	WMP	SC	DL	DS	P_{11}	WMP-TB-DL-TB-SC-TB-DS-TB
	DP	SC	DL	WF	P_{12}	WF-TB-DP-TB-DL-TB-SC-TB
	DP	SC	WP	DS	P_{13}	WP-TB-DP-TB-SC-TB-DS-TB
	DP	CP	DL	DS	P_{14}	CP-TB-DP-TB-DL-TB-DS-TB

WMP: Wet masonry partition; DP: Drywall partition; CP: Ceiling plaster; SC: Suspended ceiling; WP: Wall plaster; DL: Dry lining; WF: Wet floor; DS: Dry screed; TB: Technological break; P_w—Sequence of works in the technological model M1; P_D: Sequence of works in the technological model M2; P_1–P_{14}: Sequences of works in the technological model M3.

The total number of possible combinations depends on the number of systems and techniques for the work of partitions, ceilings, floors, and plasters in the knowledge base. The number of systems and techniques for finishing works in our knowledge base is shown in Table 5. This quantity results in a wide range of possible combinations from which clients and designers can choose and thus find the best possible solution to satisfy their requirements regarding the finishing construction works on their construction project.

Table 5. The number of systems and techniques of finishing works in the knowledge base.

Type of Finishing Work	Number	Type of Finishing Work	Number
Wet masonry partition (WMP)	107	Drywall partition (DP)	315
Ceiling plaster (CP)	248	Suspended ceiling (SC)	140
Wall plaster (WP)	236	Dry lining (DL)	103
Wet floor (WF)	207	Dry screed (DS)	62
Total	798	Total	620

For the reasons explained above, the original unit combinator was expanded into a complex COMBINATOR version. It is an inference engine that assumes the function of the unit combinator and, at the same time, allows the effects of the use of various types and combinations of DCSTs and WCSTs to be simulated, even with the values of the real quantities of the system or technique. The quantity data are entered "manually" from the bill of quantity, which is calculated or generated from the parametric 3D model of the structure. Other data (lengths of individual technological breaks with automated recalculation of cost, total labor, and weight) are generated automatically.

Once the complex COMBINATOR was developed, through a set of simulations with the help of the COMBINATOR, we measured the effects of different combinations of construction

systems and techniques on the implementation of finishing works in terms of construction time and construction cost. The effects in terms of cost and time were examined separately for: (i) combinations of only wet construction systems and techniques—technological model M1, (ii) combinations of only dry systems and techniques—technological model M2, and (iii) various combinations of wet and dry construction systems and techniques—technological model M3. The simulations were performed on the basis of quantities of partitions, ceilings, floors, and wall finishes in several reference buildings. The results of the simulations presented above represent useful data for the next analysis of the potential of dry construction systems and techniques for finishing works from several points of view, in terms of the construction time, in terms of costs, or in terms of the weight of the structures of partitions, wall finishes, floors, and ceilings. The analysis was made based on the data that resulted from all simulations of the finishing works in the reference buildings. Selected results of the analysis, exactly based on the data of the reference family house FH 70, are presented in Section 3.3. The study has continued with the two-criteria optimization analysis of construction systems and techniques for finishing processes, which has proven some responsible conclusions.

3. Results

3.1. The Complex COMBINATOR—The Knowledge System on Systems and Techniques of Finishing Works

The technological models presented above are an essential part of a complex COMBINATOR. They work on the principle of programmed macros, which, based on the selected systems, recognize the model and determine the sequence of construction work in the implementation process. Thus, technological models inform the sequencing work in the construction process. After selecting a system or technique, summary data are automatically generated for all types of the selected constructions of the given combination (partitions, ceilings, plasters, floors). Summary data on the selected combination of systems and techniques for finishing works with regard to total labor intensity, duration of technological breaks, total costs, and weight are displayed graphically.

The composition of the complex COMBINATOR is presented in Figure 3.

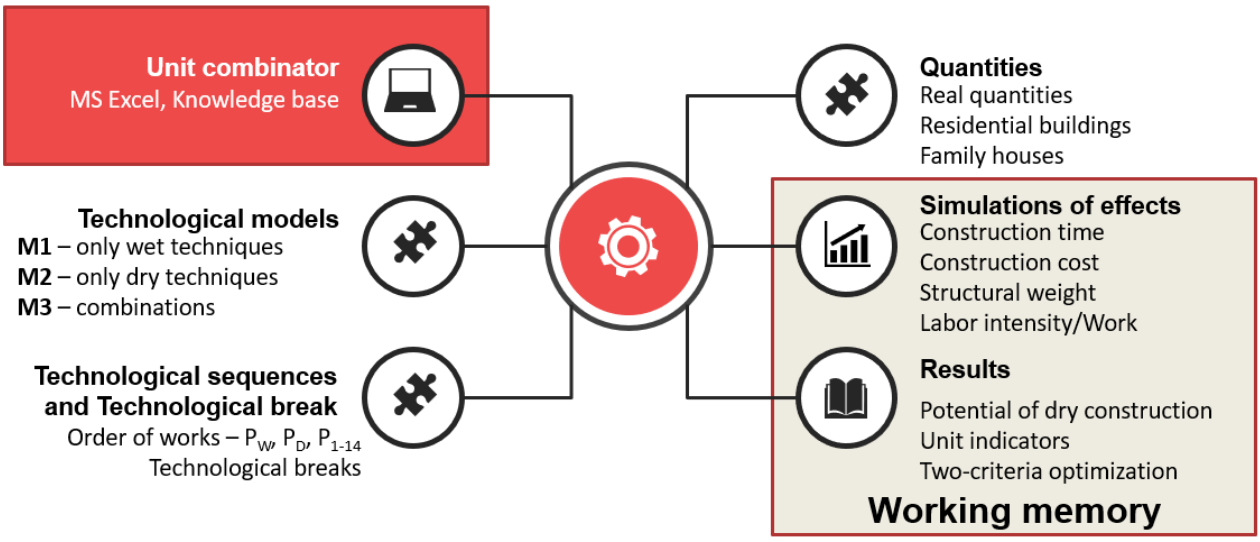


Figure 3. The composition of the complex COMBINATOR.

A sample of one of the combinations generated by the complex COMBINATOR is shown in Figure 4.

Complex COMBINATOR - combination 1							DELETE			
Partitions		**Unit cost**	**Unit labor intensity**	**Unit weight**	**TB**	**Quantity**	**Construction cost**	**Norm hours**	**Construction time**	**Weight**
Type	Wet masonry partition / Drywall partition	EUR/m^2	Nh/m^2	t/m^2	day	m^2	EUR	Nh	day	t
WMP	*Partitions made of fired bricks POROTHERM 8 P 8, on mortar POROTHERM MM 50 (80x500x238)*	*21.386*	*0.50916*	*0.085*	3	**25**	534.65	12.729	5	2.116
Ceilings		**Unit cost**	**Unit labor intensity**	**Unit weight**	**TB**	**Quantity**	**Construction cost**	**Norm hours**	**Construction time**	**Weight**
Type	Ceiling plaster / Suspended ceiling	EUR/m^2	Nh/m^2	t/m^2	day	m^2	EUR	Nh	day	t
CP	*Interior lime-cement ceiling plaster core (rough), 20 mm thick*	*12.555*	*0.58405*	*0.039*	20	**55**	690.525	32.12275	22	2.156
Plasters		**Unit cost**	**Unit labor intensity**	**Unit weight**	**TB**	**Quantity**	**Construction cost**	**Norm hours**	**Construction time**	**Weight**
Type	Wall plaster / Dry lining	EUR/m^2	Nh/m^2	t/m^2	day	m^2	EUR	Nh	day	t
WP	*Interior wall thermal insulation plaster BAUMIT, machine mixing, manual application, Thermo plaster (ThermoPutz), 20 mm thick*	*9.674*	*0.35031*	*0.030*	20	**100**	967.4	35.031	22	3.04
Floors		**Unit cost**	**Unit labor intensity**	**Unit weight**	**TB**	**Quantity**	**Construction cost**	**Norm hours**	**Construction time**	**Weight**
Typ	Wet floor / Dry screed	EUR/m^2	Nh/m^2	t/m^2	day	m^2	EUR	Nh	day	t
WF	*Cement screed (also suitable as a gradient), compressive strength 25 MPa, 50 mm thick*	*30.069*	*0.55148*	*0.110*	28	**55**	1653.795	30.3314	29	6.055
SUMMARY - combination 1		**Unit cost**	**Unit labor intensity**	**Unit weight**	**TB**	**Quantity**	**Construction cost**	**Norm hours**	**Construction time**	**Weight**
Model	Construction work sequence	EUR/m^2	Nh/m^2	t/m^2	day	m^2	EUR	Nh	day	t
M1	WMP-TB-CP-TB-WP-TB-WF-TB	73.684	1.995	0.264	71	235	3846.37	110.214	78.000	13.367

Interpretation of the combination			EUR/m 2	Nh/m^2	t/m^2	day	m^2	EUR	Nh	day	t
M1	SUMMARY - combination 1	WMP-TB-CP-TB-WP-TB-WF-TB	73.68	2.00	0.264	71	235	3846.37	110.2142	78	13.367

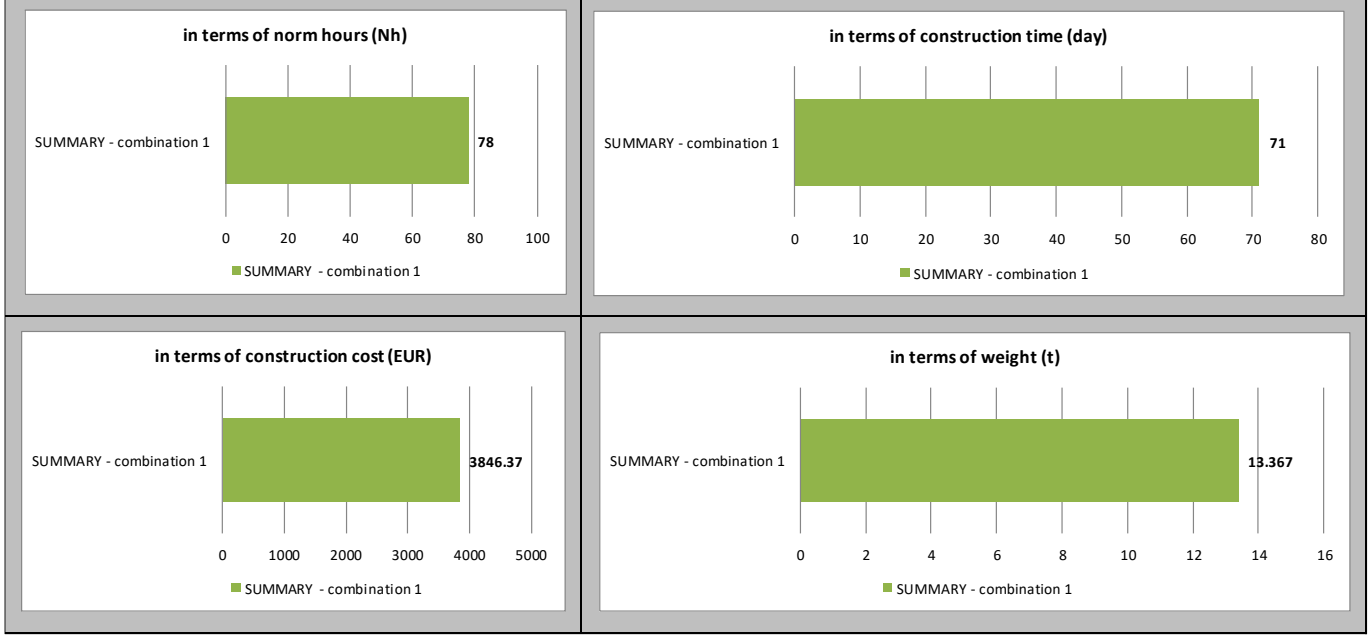


Figure 4. A sample of one combination generated by the complex COMBINATOR. WMPs: Wet masonry partitions; DPs: Drywall partitions; CPs: Ceiling plasters; SCs: Suspended ceilings; WPs: Wall plasters; DLs: Dry linings; WFs: Wet floors; DSs: Dry screeds; TB: Technological break.

The process of the selection of a combination of systems and techniques for finishing works and the generation of the relevant parameters of the selected combination by means of a complex COMBINATOR incorporates the following procedural steps: I. Selection and entry of a specific partition technique (WMPs or DPs) → entry of the total quantity.

II. Selection and entry of a specific ceiling technique (CPs or SCs) → entry of the total quantity. III. Selection and entry of a specific plaster technique (WPs or DLs) → entry of the total quantity. IV. Selection of a specific floor technique (WFs or DSs) → entry of the total quantity. V. Selection and entry of a technological model. VI. Selection and entry of the works sequence. VII. Automatic generation of the summary row of the considered combination and graphical interpretation—indication of parameters: total construction time of the considered combination of systems and techniques of finishing processes, including technological breaks, duration of TB, total costs, and total weight of the combination.

3.2. Simulations of the Effects of DCST and WCST Applications on Construction Cost and Construction Time of the Projects

The effects of DCSTs and WCSTs on the implementation of finishing works in terms of the construction time and construction cost were measured through a set of simulations that followed the development of the complex COMBINATOR. In the simulations, the average quantities of finishing construction work in different segments of residential buildings were considered. These were calculated through a desk-based survey of websites on construction projects of residential buildings and family houses constructed in Slovakia. The research sample included 50 construction projects for each type of residential construction. In the case of walls and partitions plasters, the quantity of the plaster is adjusted by counting out the quantity of the plaster on partitions when using drywall partitions. The average areas of finishing the construction work in different segments of residential buildings are presented in Table 6.

Table 6. The average areas of finishing works for different segments of residential buildings.

Building		The Average Quantities of Finishing Works [m^2]			
Residential Building	**Living Area [m^2]**	**Partitions**	**Ceilings**	**Plasters (Walls and Partitions)**	**Floors**
1-room apartment	35	10	35	55/35 *	35
2-room apartment	55	25	55	100/50 *	55
3-room apartment	75	40	75	140/60 *	75
Single-storied family house FH 150 **	125	90	125	225/90 *	125
Two-storied family house FH 70 **	100	80	100	260/105 *	100
Two-storied family house FH 100 **	150	100	150	300/120 *	150

* Counted-out the quantity of the plaster of partitions in the case of drywall partitions; ** Built-up area: 150 m^2, 70 m^2, or 100 m^2.

For a detailed analysis of the effects of DCSTs on the construction time and construction cost of construction projects, a reference project of a two-room apartment was selected from the group of apartments, and a two-storied family house FH 70 with a built-up area of 70 m^2 was selected from the family houses. The reference buildings are among the most desirable residential buildings in terms of the size of their living areas. In addition, the effects of the use of DCSTs in other buildings in the research sample were analyzed by the simulations using the resulting tool—the complex COMBINATOR. The results of the simulations inform us about the effects of the use of DCSTs on the time of finishing construction works, costs of finishing works, the total weight of finishing works, and the amount of work (norm hours) without technological breaks. All models, M1 to M3, were simulated. Ten different combinations (M1/1–10) were simulated for the M1 model, and ten different combinations (M2/1–10) were simulated for the M2 model as well. For combinations of wet and dry technologies, the M3 model, simulations were processed for different variants of the sequence of finishing works (M3/1 to M3/14). In the following chapters, selected results of simulations of the effects of DCSTs on construction time and construction costs, which were carried out on one of the two reference buildings (two-storied family house FH 70), are presented.

3.2.1. Simulations of the Effects of WCST

Ten combinations of wet finishing works—M1/1 to M1/10—for the construction of partitions, ceilings, floors, and wall plastering were individually simulated for the individual buildings in the table above (Table 6). Figure 5 shows the simulation of one of the combinations (combination M1/10) for the finishing works in the reference family house FH 70.

Complex COMBINATOR - combination M1/10											
		DELETE									
Partitions		**Unit cost**	**Unit labor intensity**	**Unit weight**	**TB**	**Quantity**	**Construction cost**	**Norm hours**	**Construction time**	**Weight**
Type	Wet masonry partition / Drywall partition	EUR/m^2	Nh/m^2	t/m^2	day	m^2	EUR	Nh	day	t
WMP	*Partitions made of fired bricks HELUZ 8 P 10 ground finish - tongue and groove, on PUR foam (80x375x249)*	*21.73*	*0.31493*	*0.05485*	3	**80**	1 738.16	25.194	6	4.388
Ceilings		**Unit cost**	**Unit labor intensity**	**Unit weight**	**TB**	**Quantity**	**Construction cost**	**Norm hours**	**Construction time**	**Weight**
Type	Ceiling plaster / Suspended ceiling	EUR/m^2	Nh/m^2	t/m^2	day	m^2	EUR	Nh	day	t
CP	*Interior gypsum ceiling plaster RIGIPS Rimano UNI 20 mm thick*	*16.98*	*0.520*	*0.029*	20	**100**	1 698.10	51.962	26	2.933
Plasters (Wall finishes)		**Unit cost**	**Unit labor intensity**	**Unit weight**	**TB**	**Quantity**	**Construction cost**	**Norm hours**	**Construction time**	**Weight**
Type	Wall plaster / Dry lining	EUR/m^2	Nh/m^2	t/m^2	day	m^2	EUR	Nh	day	t
WP	*Interior wall plaster POROTHERM UNIVERSAL, lime-cement, 15 mm thick*	*11.20*	*0.430*	*0.025*	15	**260**	2 912.26	111.813	29	6.554
Floors		**Unit cost**	**Unit labor intensity**	**Unit weight**	**TB**	**Quantity**	**Construction cost**	**Norm hours**	**Construction time**	**Weight**
Typ	Wet floor / Dry screed	EUR/m^2	Nh/m^2	t/m^2	day	m^2	EUR	Nh	day	t
WF	*Anhydrite self-leveling screed CEMIX, 090 j, class CA-C25-F6, 40 mm thick*	*22.93*	*0.229*	*0.085*	28	**100**	2 292.60	22.853	29	8.519
SUMMARY - combination M1/10		**Unit cost**	**Unit labor intensity**	**Unit weight**	**TB**	**Quantity**	**Construction cost**	**Norm hours**	**Construction time**	**Weight**
Model	Construction work sequence	EUR/m^2	Nh/m^2	t/m^2	day	m^2	EUR	Nh	day	t
M1	WMP-TB-CP-TB-WP-TB-WF-TB	72.84	1.493	0.195	66	540	8 641.12	211.822	91	22.395

Figure 5. Simulation of wet construction systems and techniques in the family house FH 70. WMPs: Wet masonry partitions; DPs: Drywall partitions; CPs: Ceiling plasters; SCs: Suspended ceilings; WPs: Wall plasters; DLs: Dry linings; WFs: Wet floors; DSs: Dry screeds; TB: Technological break; Nhs: Norm hours.

Table 7 shows the summary result of the simulation for the technological model M1P of finishing works in the reference family house FH 70, where basic indicators (total construction costs, total labor intensity, total construction time, and total weight of constructions of finishing works) are derived as average values of these indicators in ten considered combinations of finishing construction works. Since it is the technological model M1P, partitions, ceilings, floors, and wall finishes are constructed only by wet systems and techniques.

3.2.2. Simulations of the Effects of DCST

When simulating the effects of combinations of dry finishing works, i.e., combinations of systems and techniques for the second type of technological model, M2, the same procedure was used as in the previous case. In ten different combinations for the implementation of individual finishing works, only dry systems and techniques for partitions, ceilings, floors, and wall finishes were considered. Figure 6 shows the simulation of one of the combinations (combination M2/10) for the finishing works in the reference family house FH 70.

Table 7. The summary of the combinations of WCSTs in the family house FH 70.

Summary—FH 70		Total Construction Cost	Total Labor Intensity	Total Construction Time	Total Weight
Combinations		EUR	Nhs	Day	t
M1/1	WMP-TB-CP-TB-WP-TB-WF-TB	9846.34	260.413	104	28.879
M1/2	WMP-TB-CP-TB-WP-TB-WF-TB	9662.56	239.290	91	30.648
M1/3	WMP-TB-CP-TB-WP-TB-WF-TB	8102.02	214.919	86	26.254
M1/4	WMP-TB-CP-TB-WP-TB-WF-TB	10,948.90	247.090	102	31.704
M1/5	WMP-TB-CP-TB-WP-TB-WF-TB	9862.96	270.620	108	35.262
M1/6	WMP-TB-CP-TB-WP-TB-WF-TB	9450.30	200.278	84	22.697
M1/7	WMP-TB-CP-TB-WP-TB-WF-TB	8090.66	191.472	73	23.828
M1/8	WMP-TB-CP-TB-WP-TB-WF-TB	10,844.64	248.044	108	37.472
M1/9	WMP-TB-CP-TB-WP-TB-WF-TB	8926.98	256.640	99	30.618
M1/10	WMP-TB-CP-TB-WP-TB-WF-TB	8641.12	211.822	91	22.395
M1P	Average	9437.65	234.06	95	28.98

WMP: Wet masonry partition; DP: Drywall partition; CP: Ceiling plaster; SC: Suspended ceiling; WP: Wall plaster; DL: Dry lining; WF: Wet floor; DS: Dry screed; TB—Technological break; Nhs: Norm hours.

Complex COMBINATOR - combination M2/10 DELETE

ATOR		Unit cost	Unit labor intensity	Unit weight	TB	Quantity	Construction cost	Norm hours	Construction time	Weight
Type	Wet masonry partition / Drywall partition	EUR/m²	Nh/m²	t/m²	day	m²	EUR	Nh	day	t
DP	*Plasterboard partition wall Rigips 75 mm thick, one-side sheathed with RB 12.5 mm boards, CW 50*	*25.271*	*0.91484*	*0.0217*	1	**80**	2 021.68	73.187	10	1.736
Ceilings		**Unit cost**	**Unit labor intensity**	**Unit weight**	**TB**	**Quantity**	**Construction cost**	**Norm hours**	**Construction time**	**Weight**
Type	Ceiling plaster / Suspended ceiling	EUR/m²	Nh/m²	t/m²	day	m²	EUR	Nh	day	t
SC	*Rigips coffered ceiling 600 x 600 mm, edge A, structure visible, Casoprano Casobianca white board*	*33.186*	*0.76965*	*0.00812*	0	**100**	3 318.60	76.965	10	0.812
Plasters (Wall finishes)		**Unit cost**	**Unit labor intensity**	**Unit weight**	**TB**	**Quantity**	**Construction cost**	**Norm hours**	**Construction time**	**Weight**
Type	Wall plaster / Dry lining	EUR/m²	Nh/m²	t/m²	day	m²	EUR	Nh	day	t
DL	*Wall lining with RIGIPS plasterboard, construction thickness 25 mm, RB board 12.5 mm*	*15.88*	*0.69928*	*0.01755*	2	**105**	1 667.40	73.424	11	1.84275
Floors		**Unit cost**	**Unit labor intensity**	**Unit weight**	**TB**	**Quantity**	**Construction cost**	**Norm hours**	**Construction time**	**Weight**
Typ	Wet floor / Dry screed	EUR/m²	Nh/m²	t/m²	day	m²	EUR	Nh	day	t
DS	*Plasterboard dry floor RIGIPS RIGIDUR E20, 20 mm thick, with 20 mm thick dry underlay*	*42.795*	*1.17769*	*0.03635*	1	**100**	4 279.50	117.769	6	3.635
SUMMARY - combination M2/10		**Unit cost**	**Unit labor intensity**	**Unit weight**	**TB**	**Quantity**	**Construction cost**	**Norm hours**	**Construction time**	**Weight**
Model	Construction work sequence	EUR/m²	Nh/m²	t/m²	day	m²	EUR	Nh	day	t
M1	DP-TB-DL-TB-SC-TB-DS-TB	117.13	3.561	0.084	4	385	11 287.18	341.346	37	8.026

Figure 6. Simulation of dry construction systems and techniques in the family house FH 70. WMP: Wet masonry partition; DP: Drywall partition; CP: Ceiling plaster; SC: Suspended ceiling; WP: Wall plaster; DL: Dry lining; WF: Wet floor; DS: Dry screed; TB: Technological break; Nhs: Norm hours.

Table 8 shows the summary result of the simulation for the technological model M2P of finishing works in the reference family house FH 70, where basic indicators (total construction costs, total labor intensity, total construction time, and total weight of constructions of finishing works) are derived as average values of these indicators in ten considered combinations of finishing construction works. Since it is the technological model M2P, partitions, ceilings, floors, and wall finishes are constructed only by dry systems and techniques.

Table 8. The summary of the combinations of DCSTs in the family house FH 70.

Summary—FH 70		Total Construction Cost	Total Labor Intensity	Total Construction Time	Total Weight
Combinations		EUR	Nhs	Day	t
M2/1	DP-TB-DL-TB-SC-TB-DS-TB	9805.21	338.634	39	7.716
M2/2	DP-TB-DL-TB-SC-TB-DS-TB	10,023.45	338.872	39	7.780
M2/3	DP-TB-DL-TB-SC-TB-DS-TB	10,870.41	339.024	39	7.884
M2/4	DP-TB-DL-TB-SC-TB-DS-TB	11,484.17	337.618	37	8.158
M2/5	DP-TB-DL-TB-SC-TB-DS-TB	10,278.25	339.969	39	8.397
M2/6	DP-TB-DL-TB-SC-TB-DS-TB	9698.48	329.888	38	8.117
M2/7	DP-TB-DL-TB-SC-TB-DS-TB	10,441.24	344.639	39	8.658
M2/8	DP-TB-DL-TB-SC-TB-DS-TB	11,588.01	389.940	44	9.593
M2/9	DP-TB-DL-TB-SC-TB-DS-TB	11,107.75	322.227	36	7.498
M2/10	DP-TB-DL-TB-SC-TB-DS-TB	11,287.18	341.346	37	8.026
M2P	Average	10,658.42	342.22	39	8.18

WMP: Wet masonry partition; DP: Drywall partition; CP: Ceiling plaster; SC: Suspended ceiling; WP: Wall plaster; DL: Dry lining; WF: Wet floor; DS: Dry screed; TB: Technological break; Nhs: Norm hours.

3.2.3. Simulations of the Effects of Combinations of DCSTs and WCSTs

In the same way, various combinations of dry and wet systems and techniques for the implementation of finishing works in the reference family house FH were simulated. The third type of basic technological model included relevant combinations of the sequence of construction works from P1 to P14 in accordance with the methodology that was presented in Chapter 2.3. Figure 7 shows the simulation of one of the combinations (combination M3/14) for the finishing works in the reference family house FH 70, where three dry construction techniques (drywall partitions, dry linings, and dry screed) and one traditional wet technique (ceiling plaster) are combined.

Complex COMBINATOR - combination M3/14								DELETE			
Partitions		Unit cost	Unit labor intensity	Unit weight	TB	Quantity	Construction cost	Norm hours	Construction time	Weight
Type	Wet masonry partition / Drywall partition	EUR/m²	Nh/m²	t/m²	day	m²	EUR	Nh	day	t
DP	*Plasterboard partition wall Rigips 75 mm thick, one-side sheathed with RFI 12.5 mm board, CW 50*	*29.37*	*0.923*	*0.031*	1	**80**	2 349.44	73.810	10	2.492
Ceilings		Unit cost	Unit labor intensity	Unit weight	TB	Quantity	Construction cost	Norm hours	Construction time	Weight
Type	Ceiling plaster / Suspended ceiling	EUR/m²	Nh/m²	t/m²	day	m²	EUR	Nh	day	t
CP	*Interior gypsum ceiling plaster RIGIPS Rimano UNI 15 mm thick*	*14.8*	*0.479*	*0.022*	15	**100**	1 407.60	47.871	21	2.200
Plasters (Walll finishes)		Unit cost	Unit labor intensity	Unit weight	TB	Quantity	Construction cost	Norm hours	Construction time	Weight
Type	Wall plaster / Dry lining	EUR/m²	Nh/m²	t/m²	day	m²	EUR	Nh	day	t
DL	*Wall lining with RIGIPS plasterboard, construction thickness 25 mm, RB board 12.5 mm*	*15.88*	*0.699*	*0.018*	2	**105**	1 667.40	73.424	11	1.84275
Floors		Unit cost	Unit labor intensity	Unit weight	TB	Quantity	Construction cost	Norm hours	Construction time	Weight
Typ	Wet floor / Dry screed	EUR/m²	Nh/m²	t/m²	day	m²	EUR	Nh	day	t
DS	*Plasterboard dry floor RIGIPS RIGIDUR E25, 25 mm thick, without underlay*	*38.25*	*0.984*	*0.032*	1	**100**	3 824.70	98.444	5	3.165
SUMMARY - combination M3/14		Unit cost	Unit labor intensity	Unit weight	TB	Quantity	Construction cost	Norm hours	Construction time	Weight
Model	Construction work sequence	EUR/m²	Nh/m²	t/m²	day	m²	EUR	Nh	day	t
M1	CP-TB-DP-TB-DL-TB-DS-TB	97.57	3.085	0.102	19	385	9 249.14	293.550	47	9.700

Figure 7. Simulation of combinations of DCSTs and WCSTs in the family house FH 70. WMP: Wet masonry partition; DP: Drywall partition; CP: Ceiling plaster; SC: Suspended ceiling; WP: Wall plaster; DL: Dry lining; WF: Wet floor; DS: Dry screeds TB: Technological break; Nhs: Norm hours.

Table 9 presents the summary result of the simulation for the technological model M3P of finishing works in the reference family house FH 70, where basic indicators (total construction costs, total labor intensity, total construction time, and total weight of constructions of finishing works) are derived as average values of these indicators in fourteen considered combinations of finishing construction works. Since it is the technological model M3P, partitions, ceilings, floors, and wall finishes are constructed by both dry and traditional wet systems and techniques.

Table 9. The summary of the combinations of DCSTs and WCSTs in the family house FH 70.

Summary—FH 70		Total Construction Cost	Total Labor Intensity	Total Construction Time	Total Weight
Combinations		EUR	Nhs	Day	t
M3/1	WMP-TB-CP-TB-WP-TB-DS-TB	9469.60	284.838	61	16.577
M3/2	WMP-TB-CP-TB-WF-TB-DL-TB	9300.98	296.614	83	24.503
M3/3	WMP-TB-WP-TB-WF-TB-SC-TB	11,795.82	235.833	78	26.771
M3/4	CP-TB-WP-TB-WF-TB-DP-TB	6697.85	201.912	78	16.879
M3/5	WMP-TB-CP-TB-DL-TB-DS-TB	10,136.64	370.903	52	16.569
M3/6	WMP-TB-WP-TB-SC-TB-DS-TB	10,072.58	330.630	58	20.166
M3/7	CP-TB-WP-TB-DP-TB-DS-TB	7807.01	254.158	53	8.789
M3/8	WMP-TB-WF-TB-DL-TB-SC-TB	9661.06	322.923	72	19.340
M3/9	WP-TP-WF-TP-DP-TB-SC-TB	7854.58	229.957	77	15.653
M3/10	CP-TB-WF-TB-DP-TB-DL-TB	7185.04	237.509	84	18.008
M3/11	WMP-TB-DL-TB-SC-TB-DS-TB	11,969.74	419.298	51	17.894
M3/12	WF-TB-DP-TB-DL-TB-SC-TB	8486.34	269.015	63	16.437
M3/13	CP-TB-DP-TB-SC-TB-DS-TB	10,340.61	321.533	47	10.236
M3/14	CP-TB-DP-TB-DL-TB-DS-TB	9249.14	293.550	47	9.700
M3P	Average	9287.64	290.62	60	15.28

WMP: Wet masonry partition; DP: Drywall partition; CP: Ceiling plaster; SC: Suspended ceiling; WP: Wall plaster; DL: Dry linings; WF: Wet floor; DS: Dry screed; TB—Technological break; Nhs: Norm hours.

3.3. The Analysis of the Dry Construction Potential in Finishing Construction Works

The results of the simulations presented above represent useful data for the next analysis of the potential of dry construction systems and techniques for finishing works from several points of view, in terms of the construction time, in terms of costs, or in terms of the weight of the structures of partitions, wall finishes, floors, and ceilings.

Regarding the construction time of the finishing works, Figure 8 presents the total construction time of the finishing works in the reference family house FH 70, for all simulated combinations of systems and techniques separately. For a faster and clearer evaluation, the shortest construction times within the examined combinations of individual technological models are highlighted in dark green, and the longest construction times are highlighted in deep red. The average values of the time parameter in technological models M1P, M2P, M3P are also highlighted in the colors corresponding to each model: models M1—blue, M2—yellow, and M3—green.

As for the technological model M1, which includes only wet systems and techniques, the construction time ranges from a minimum time of 73 days to the longest implementation of finishing works in the case of combinations M1/5 and M1/7, where the construction time is 108 days. The average value of the construction time in the case of combinations of wet construction systems and techniques is 95 days. This time directly depends on the choice of technique and is strongly dependent on the duration of technological breaks after individual works. The construction time in the case of combinations of only dry finishing works (technological model M2) is from 36 days (M2/9) to a maximum of 44 days (M2/8). The average value of the construction time for finishing works in the case of combinations of only dry construction systems and techniques is 39 days. In the case of the technological model M3, in which dry and wet construction systems and techniques are combined in each of the individual combinations of the finishing works (partitions, ceilings, floors,

and wall finishes), the construction time is a minimum of 47 days (M3/13 and M3/14) and a maximum of 84 days (M3/10). Compared to MP1, the average construction time is reduced by 12% to 50%, on average by 32%. From the above results, it can be concluded that by choosing only dry techniques, the time for the completion of finishing works can be reduced by 40% to 66% compared to the use of wet construction systems and techniques. In terms of average values, there is a reduction of days by almost 60%. By choosing at least one construction work implemented with dry techniques, the implementation time is reduced by 12%; by choosing three dry techniques, it can be reduced by 50%.

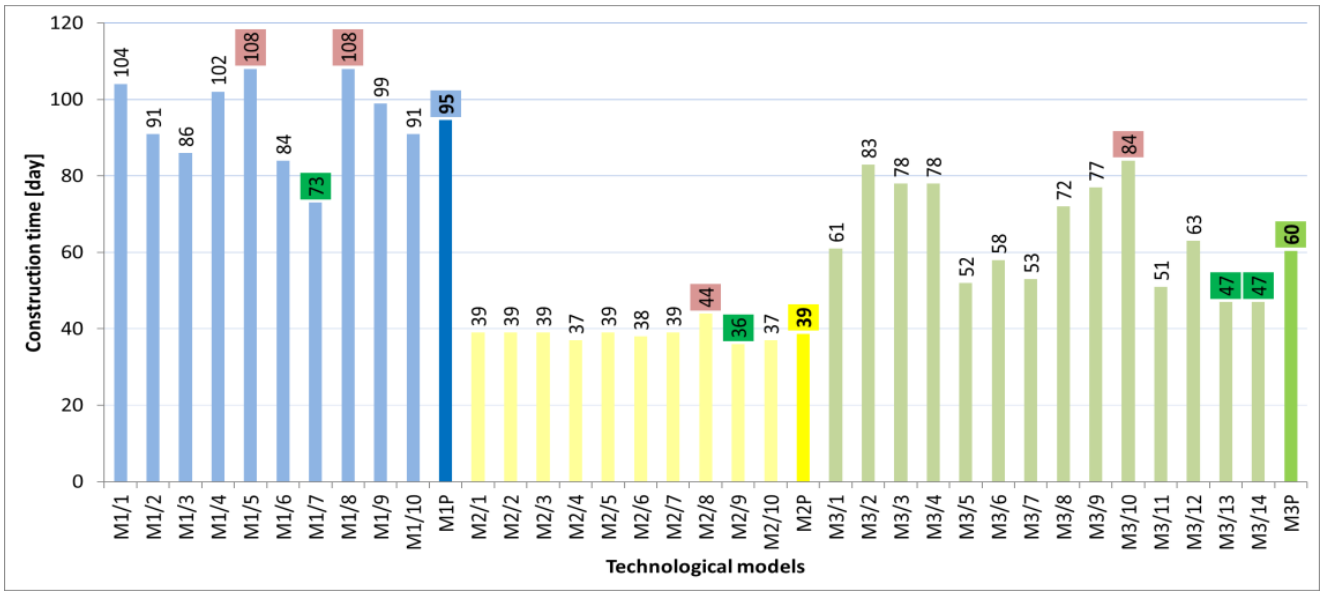


Figure 8. Construction time of different technological models of finishing works in the family house FH 70.

In a similar way, the analysis of the construction time was carried out for apartments with different numbers of living rooms, for a family house with an area of 100 m^2, and for a one-storied family house. Based on the results of the analyses presented above, the potential of DCSTs was clearly confirmed in terms of construction time, both for residential buildings and for family houses.

Several sources mention the increased construction cost as one of the disadvantages of dry construction techniques compared to traditional wet techniques. Although these increased costs were confirmed by our simulations, the ensuing analyses point to several cases where the costs of dry construction are comparable to the costs of traditional construction or combinations of dry and wet technologies (technological model M3) and even lower. Figure 9 shows the total construction cost of the finishing works in the reference family house FH 70, for all simulated combinations separately. For a faster and clearer evaluation, the lowest construction cost within the examined combinations of individual technological models is highlighted in dark green, and the highest construction cost is in deep red. The average values of the cost parameter in technological models M1P, M2P, and M3P are also highlighted in the colors corresponding to each model: models M1—blue, M2—yellow, and M3—green.

The construction cost of finishing works in the case of technological model M1, which includes combinations of only wet technologies, is from a minimum of EUR 8091 (M1/7) to a maximum of EUR 10,949 (M1/4). The average cost is EUR 9438. If the combinations of finishing works include only dry construction systems and techniques (technological model M2), the construction cost is a minimum of EUR 9698 (M2/6) and a maximum of EUR 11,588 (M2/8). The average construction cost in the technological model M2 is EUR 10,658. To compare dry techniques with traditional wet techniques, we can confirm an increase in costs by 12% to 43%, but there are also combinations when the costs of dry technologies are

lower. The construction cost in the case of combining dry construction techniques together with traditional wet construction techniques in individual combinations of the technological model M3 is a minimum of EUR 6698 (M3/4) and a maximum of EUR 11,970 (M3/11). The average cost in the technology model M3 is EUR 9288. The value of the average cost of the combination of dry and wet techniques, M3P, is lower compared to the value of wet techniques, M1P, by 1.6% and compared to the average cost of dry techniques, M2P, by 13%. In the same way, the analysis of construction cost was carried out for apartments with different numbers of living rooms, for a family house with an area of 100 m^2, and for a one-storied family house.

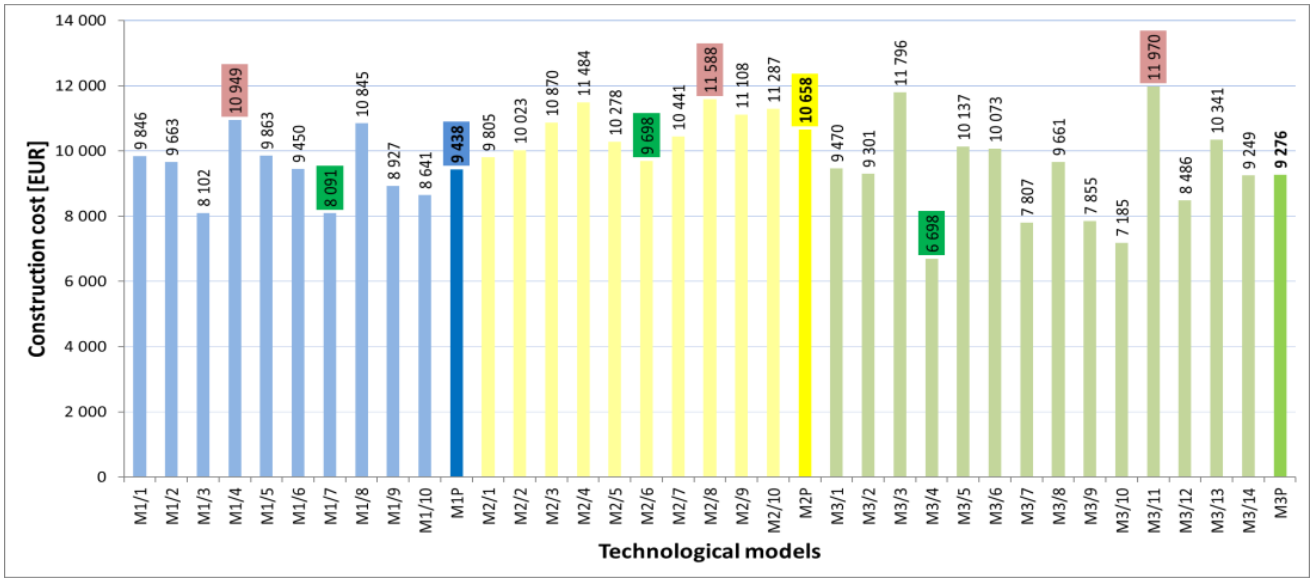


Figure 9. Construction cost of different technological models of finishing works in the family house FH 70.

From the results of the analysis, it follows that by choosing only dry construction systems and techniques, the construction cost will increase in the range of 12% to 43% of the cost of wet construction systems and techniques. Considering the average values of dry M2P to wet M1P, the cost increase is 12%. By choosing at least one of the finishing works for a dry technique, the cost is reduced by a maximum of 39% compared to wet techniques in the model M1; by choosing three finishing works with dry systems or techniques, the cost could increase by 48%. The average cost of combinations of dry and wet technologies in the technological model M3P are reduced in comparison with wet techniques in M1 by 1.6%, and compared to the average cost of dry techniques in M2P by even 13%.

Although the potential of dry construction in terms of costs has not been clearly demonstrated, the results of the simulations of the technological model M2 compared to the combinations of wet techniques in the technological model M1 show increased costs, but by choosing a suitable combination of dry and wet techniques, it is also possible to achieve a reduction in construction costs.

Manufacturers, sellers, and building companies expressly declare the advantage of dry construction in terms of structure weight. Figure 10 presents the total weight of partitions, ceilings, wall finishes and floors in the reference family house FH 70, for all examined technology combinations separately. For a faster and clearer evaluation, the lowest structural weights within the examined combinations of individual technological models are highlighted in dark green; the highest structural weights are in deep red. The average values of the weight parameter in technological models M1P, M2P, M3P are also highlighted in the colors corresponding to each model: models M1—blue, M2—yellow, and M3—green.

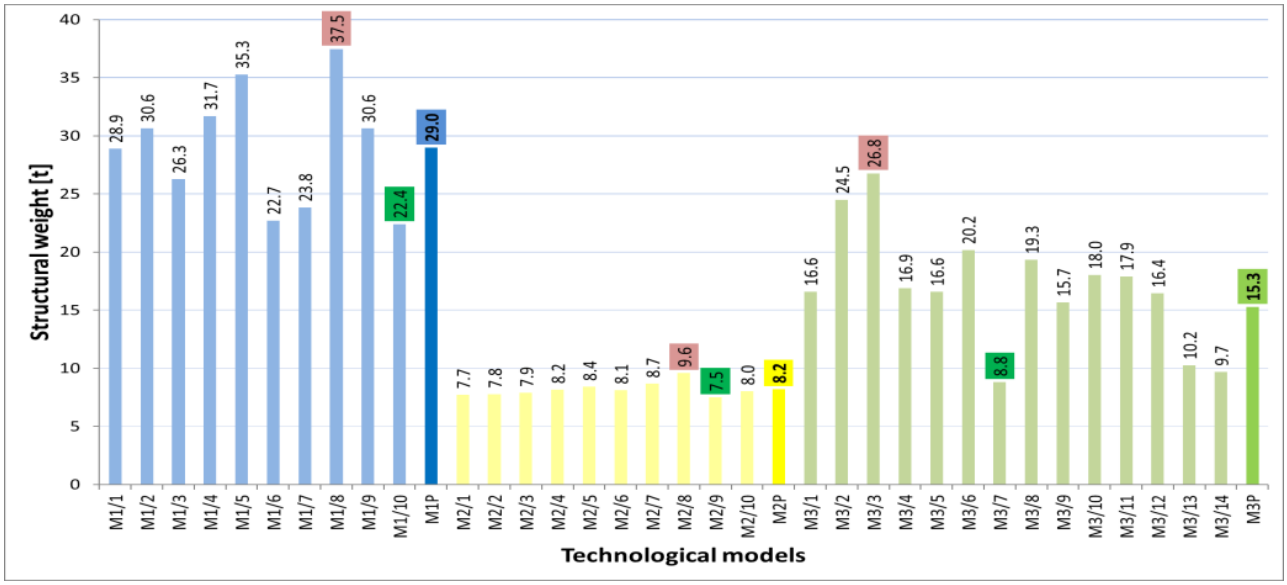


Figure 10. Structural weight of different technological models of finishing works in the family house FH 70.

The weight of constructions of finishing works in combinations of only wet techniques (technological model M1) is from a minimum of 22.4 tons to a maximum of 37.5 tons. The average value for M1P is 29.0 tons. The structural weight of finishing works in combinations of only dry techniques (technological model M2) is from a minimum of 7.5 tons to a maximum of 9.6 tons. The average weight in M2P is 8.2 tons. Compared to the M1 model, where only wet systems and techniques are applied, the weight is reduced by 58% to 80%. The structural weight of finishing works in combinations where wet techniques are combined with dry techniques (technological model M3) is from 8.8 tons to a maximum of 26.8 tons. The average structural weight of finishing works in the technological model M3P is 15.3 tons.

By choosing only dry systems and techniques, the weight is reduced in the range of 58% to 80% of the weight of only wet techniques. As for the average weight of the M2P model with only dry techniques, there is a decrease of 72% compared to the average weight of the M1P model with only wet construction systems and techniques for finishing works. By choosing at least one finishing work performed by a dry technique, the weight can be reduced by a maximum of 30% compared to the M1 model with only wet techniques. By choosing three dry techniques in combination with one wet system or technique, the structural weight could be reduced by 61%. The average structural weight in combinations of dry and wet techniques can be reduced by 41% compared to the average weight of wet systems and techniques.

3.4. Optimization-Based Selection of Systems and Techniques of Finishing Works

Considering the proven conflicting results in assessing the potential of dry construction —dry construction systems and techniques are faster in terms of construction time but more expensive, and vice versa, wet construction techniques are cheaper but more time-consuming—we decided to use a simple two-criteria optimization, the principle of which is an objective determination of weights for decision-making based on two criteria, namely the construction time and construction cost of finishing works. In order to objectify the weights of the criteria in the two-criteria decision-making, these were determined based on the results of a questionnaire survey. The survey was focused on the perception of requirements for construction projects by potential clients in construction. Due to addressing the respondents through several online platforms and social networks, an indefinite number of respondents from different age categories with different levels of education and a different range of preferences in the area of housing were addressed. The collection of

responses to the survey took one month, and during that time, responses were collected from 236 different respondents. The results of the survey confirmed a clear focus on the construction cost. The importance of individual criteria was assessed using the scoring method; that is, based on the number of points assigned by individual respondents. The scoring scale from 1 to 5 made it possible to express the subjective preferences of each of the respondents. Points allocated to individual criteria were converted to normalized weights as follows: weight of the construction cost criterion is 80% and weight of the construction time criterion is 20%. However, to demonstrate the potential of dry construction against traditional wet construction techniques, the criteria weight ratio was extended by other variants, as follows:

- Variant V1: the client is hesitative—50% construction time and 50% construction cost;
- Variant V2: the client prefers a shorter construction time—70% construction time and 30% construction cost;
- Variant V3: the client prefers a lower construction cost—20% construction time and 80% construction cost.

Figure 11 presents a graphic evaluation of individual variants for choosing a combination of systems and techniques for finishing processes according to the criteria presented above, which was performed for the specific case of a reference family house FH 70. Through the complex COMBINATOR developed by us, it is easy to simulate the results for different combinations of dry and wet construction techniques, while taking into account all three variants of the weights ratios of the construction time and construction cost decision criteria. When displaying the results of the advantages of wet or dry finishing systems and techniques, such two-criterion graphs do not contain data for the technological variant M3, which combines dry techniques with wet techniques in each of the combinations of finishing works. There are only results for the technological variant M1 (combinations of only traditional WCSTs) and for the technological variant M2 (combinations of only DCSTs). This makes the results of the variation of dry and wet construction clearer. For individual weight variants of the decision-making criteria, whose interfaces are represented in the graph by vertical lines from V1 to V3, it is possible to read unit indicators of construction time and construction costs of individual technological models from M1/1 to M1/10 (combinations of only wet construction systems and techniques) and in technological models from M2/1 to M2/10 (combinations of only dry construction systems and techniques). Based on these unit indicators, it is possible to decide individually, for different variants of criteria weights, on the advantage or disadvantage of dry construction systems and techniques in terms of construction time and construction costs.

The unit indicators of construction cost parameter (EUR/m^2 of living area) and construction time parameter (day/m^2 of living area) are derived from the total values of these parameters, which were presented as the results of our simulations for the reference family house FH 70 in Tables 7–9.

To evaluate the potential of dry construction systems and techniques for the family house RD 70 in question, the following conclusions can be drawn on the basis of two-criteria optimization:

- Variant V1 (50%/50%)—dry construction is comparable and competitive with wet construction, a slight advantage of dry construction;
- Variant V2 (70%/30%)—the potential of dry construction due to the advantage of a short construction time is clearly confirmed;
- Variant V3 (20%/80%)—the advantage of combinations of only wet construction systems and techniques has been proven, but apart from the most advantageous four combinations, the dry construction could be regarded as comparable and competitive.

The following conclusions also came from the study dealing with the selection of techniques for finishing processes in the reference family house FH 70:

- If the weight of the "construction time" criterion is in the interval from 0% to 25% and the weight of the "cost" criterion is in the interval from 75% to 100%, wet construction is more advantageous;
- If the weight of the "construction time" criterion is in the interval from 25% to 55%, and therefore the weight of the "cost" criterion is in the interval from 45% to 75%, the dry and wet construction methods are comparable and competitive;
- If the weight of the "construction time" criterion is in the interval from 55% to 100%, and therefore the weight of the "cost" criterion is from 0% to 45%, dry construction is more advantageous.

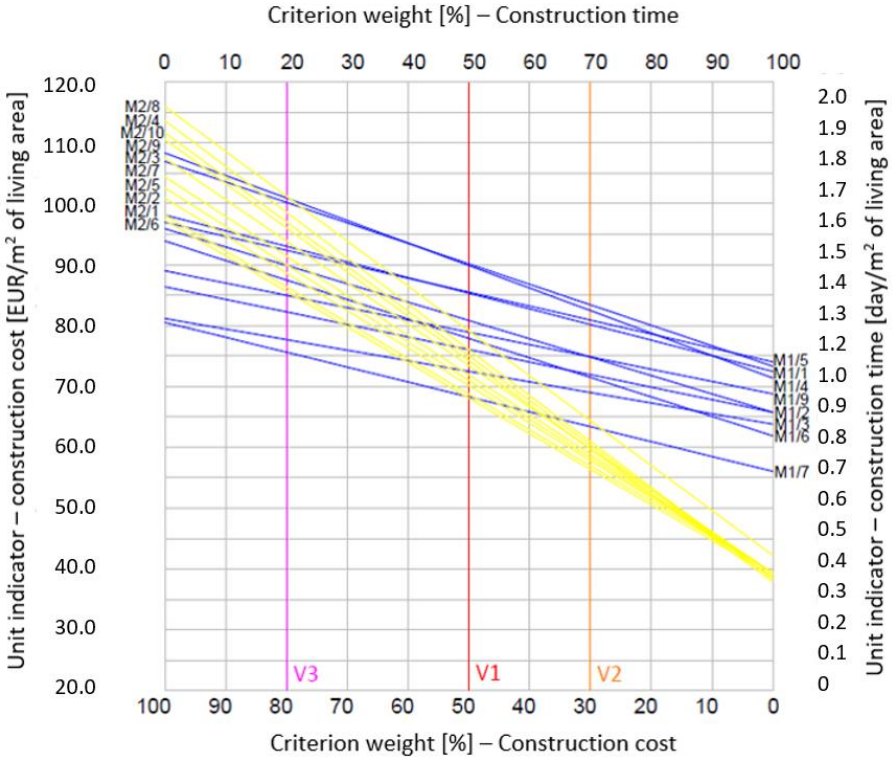


Figure 11. Graphical interpretation of the evaluation of the advantages of combinations of dry and wet construction systems and techniques of finishing works for RD 70.

4. Discussion and Conclusions

Due to the current large number of construction systems and techniques that the market offers for various phases of the construction of residential buildings, from the foundation, through the skeleton construction, to the finishing works, investors can decide on the basis of various criteria which construction systems and techniques they will lean towards. Some still prefer traditional construction methods, in other words "wet construction", others choose "dry construction" techniques or the possibility of combining wet and dry construction systems and techniques. The construction industry is moving towards efficient processes in terms of costs and time; therefore, when designing and assessing the project, clients emphasize the amount of necessary funds and the time or date when they will be able to use the building or hand it over for use.

Existing research suggests that knowledge systems will become one of the important means of knowledge management in the future. Knowledge graph application is research focused on specific problems using multiple technologies [40,41]. Our research can also be included among such technologies. Due to the decentralization and complexity of knowledge in architecture, engineering, and construction, research on knowledge graphs is still insufficient [42].

In our research, emphasis is placed on the correct analysis and consequential selection of suitable materials according to the requirements for the construction of final building

structures, similar to what has been conducted in other research studies [43,44]. When considering the construction of dry gypsum-based linings, it is possible to state that these are recognized as ecological and efficient materials suitable for modern construction. The mechanical properties of gypsum-based composites are decisive for determining their suitability for various applications, which also applies to the application of dry linings [45].

When choosing a system or technique for finishing processes, the costs and construction time are decisive [46,47]. The study presented offers an exploration of these connections through a knowledge system designed and developed by us. Its knowledge base includes a knowledge-based arrangement of time and cost parameters of 798 selected traditional wet systems and techniques and 620 modern dry systems and techniques to construct partitions, wall finishes, ceilings, and floors. The inference engine of the knowledge system—the complex COMBINATOR—allows the effects of using different types and combinations of DCSTs within the finishing works to be simulated. The tool evaluates the combinations in terms of time and cost parameters (construction time, labor intensity in norm hours, the length of technological breaks, and construction cost) and the weight of the partitions, ceilings, floors, and wall finishes. Simulation modeling has been one of the most well-known decision support strategies for many years. [48,49].

Our research is beneficial due to its most significant outputs:

- A complete set of dry and wet construction systems and techniques for finishing works (partitions, ceilings, wall finishes, and floors) was developed. The knowledge base prepared by us includes characteristics and information on structural, cost, and time parameters, which can help clients in making decisions and choosing a system and technique, designers in the processing and design of project documentation, and contractors in the implementation of finishing processes.
- The inference engine of the knowledge system allows different combinations of dry and wet systems and techniques for finishing processes to be simulated and thus examine the effects in the area of cost and time parameters.

By simulating through the complex COMBINATOR, it was possible to analyze the potential of dry construction against traditional wet construction in relation to the time, costs, weight, and labor intensity of individual techniques and systems of finishing works. Several conclusions were drawn based on the results of the simulations. By choosing only dry systems and techniques, the construction time can be reduced by between 40% and 80% of the days of construction with only wet works. In the construction of partitions, ceilings, wall finishes, and floors in residential buildings, when combining wet and dry construction techniques, the construction time can be reduced by 12% when choosing at least one dry system or technique, and by 50% when choosing three dry systems and techniques. In terms of construction time, the potential of dry finishing works was confirmed. By choosing only dry techniques, construction costs will increase by at least 12% and at most by 43% of the cost of wet construction systems and techniques. When combining wet techniques together with dry ones, by choosing at least one work made by a dry technique, the costs can be below the level of the costs of wet systems and techniques; by choosing three construction works made by dry techniques, the costs can reach a 36% to 39% increase compared to wet technologies. The potential in terms of costs was not confirmed, even though there were combinations of dry techniques that achieved competitive or more favorable costs compared to wet construction systems and techniques. By choosing only dry techniques, the weight is reduced by at least 50% to 80% of the weight of wet finishing works. Weight reduction is already demonstrated when choosing at least one work made by a dry technique (reduction max. 30%); when choosing three dry works made by dry techniques, the structural weight of partitions, ceilings, wall finishes, and floors may be reduced by 60% compared to wet techniques application only. The potential of dry construction in terms of weight has been clearly confirmed. By choosing only dry techniques, labor intensity will increase by at least 16%, and a maximum of 57%, of the labor intensity of wet works. By choosing dry systems and techniques, the labor intensity of finishing construction works increases; by choosing one work made by dry technique, the labor intensity increases by at least 9%; by

choosing three, labor intensity increases by a maximum of 54%. The growing labor intensity due to the implementation of dry techniques requires more skills, which are subsequently reflected in the increase in the costs of dry construction.

Some research studies have dealt with advantages as well as the obstacles to the greater use of dry construction [50–52]. In the study presented, the potential and competitiveness of dry construction in relation to traditional wet construction techniques was demonstrated by two-criteria optimization of the selection of combinations of systems and techniques for the finishing works of partitions, ceilings, wall finishes, and floors in a reference example of a family house. Based on the almost identical results of the two-criterion optimization of the selection of techniques for finishing works in residential buildings and family houses with the assignment of criteria weights (construction time criterion, construction cost criterion) in the presented study, some conclusions and recommendations for clients can be drawn. If the client prefers a short construction time (with a weight of time criterion from 55% to 100%) when making a decision, dry construction is more efficient and advantageous. If they prefer lower costs in their decision-making (with a weight of cost criterion from 75% to 100%), wet construction is more efficient and advantageous. If they are hesitative (50%/50%), then the construction methods for finishing work are comparable and competitive; dry construction even has a slight advantage. If they are hesitative (50%/50% weight of both criteria), then both wet and dry construction methods for finishing works are comparable and competitive; dry construction even has a slight advantage.

The results of this study cover a complete set of processed DCSTs, a knowledge base including characteristics and information on construction, cost, and time parameters, which can help clients in making decisions and choosing the best options of system and technique, designers in design preparing, and contractors in implementation finishing processes. The developed inference mechanism makes it possible to create different combinations of dry and wet systems and techniques of finishing processes, to simulate the effects in the area of cost and time, and thus to demonstrate the potential of dry construction methods. Additionally, a set of unit indicators for the finishing works was obtained in terms of construction time (day/m^2 of living area) and construction costs (EUR/m^2 of living area). The practical implications consist of demonstrating the potential of DCSTs for the finishing works in newly built buildings or renovations. The developed inference mechanism allows:

- For simulating the effects of systems and techniques of finishing works in terms of costs, construction time, and weight, thereby demonstrating the benefits, or restrictions on selected combinations of DCSTs and WCSTs;
- The improvement of the demonstration of the advantages of dry construction and automatic comparisons. It will bring a decisive criterion for the selection of the system and technique, and to more effectively design systems and techniques of finishing works in terms of cost, construction time, and structural weight;
- For enhanced understanding and knowledge of the systems and techniques of the finishing works from the designers' side when consulting with clients, a more effective evaluation of the finishing works in the budgeting office, and a better acquisition of the technological procedures and planning for the execution of the order for the contractor;
- Programmers and developers of the CENKROS 4 construction software to reconsider the creation of a similar tool (module) that could simulate and vary selected construction systems and techniques.

A recommendation for further research is the processing of a complex decision-making system with the assignment of weights for the examined effects (construction time and construction costs), other effects (e.g., weight, environmental, sustainability parameters) and preferences of individual finishing works—if the client prefers the selected type of technique, e.g., only wall plasters instead of dry lining, only suspended ceilings instead of ceiling plasters, wet floors instead of dry screeds, and wet masonry partition instead of drywall partitions. The result of this optimization would be a selection according to the

ideas and requirements of the investor. The result of such optimization would be a choice according to more ideas and requirements of the client.

Author Contributions: Conceptualization, M.K., A.D. and Z.S.; methodology, M.K. and A.D.; software, A.D.; validation, A.D., Z.S. and A.T.; formal analysis, A.D. and A.T.; investigation, M.K. and A.D.; resources, A.D. and A.T.; data curation, A.D. and Z.S.; writing—original draft preparation, A.D., Z.S. and A.T.; writing—review and editing, M.K., A.D., Z.S. and A.T.; visualization, Z.S. and A.T.; supervision, M.K.; project administration, M.K.; funding acquisition, M.K. All authors have read and agreed to the published version of the manuscript.

Funding: The work was supported by the grant VEGA 1/0336/22 "Research on the effects of Lean Production/Lean Construction methods on increasing the efficiency of on-site construction technologies".

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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