ADVANCES IN FORESTRY SCIENCE

OPEN ACCESS

Monitoring checklist for the construction of light-woodframe houses

Bruno Chiaramonti[1] *Victor De Araujo*[2,3] *Glaucia Prates*[3] *Antonio Savi*[3] *Juliana Cortez-Barbosa*[3]

1 M7 Investments, Diretoria de Investimentos Alta Renda, 14110-000, Ribeirão Preto - SP, Brasil
2 Universidade Federal de São Carlos, Programa de Pós-Graduação em Engenharia Civil, Campus São Carlos, Rodovia Washington Luis km235, 13565-905, São Carlos - SP, Brasil
3 Universidade Estadual Paulista, Instituto de Ciências e Engenharia, Campus de Itapeva, Rua Geraldo Alckmin 519, 18409-010, Itapeva - SP, Brasil

Original Article

***Corresponding author:**
engim.victor@gmail.com
victor@ufscar.br

Keywords:
Light framing
Construction industry
Organizational tool
Wooden houses

Palavras-chave:
Estrutura leve
Indústria da construção
Ferramenta organizacional
Casas de madeira

Received in
2023/05/30

Accepted on
2023/11/23

Published in
2023/12/31

DOI:
http://dx.doi.org/10.34062/afs.v10i4.15638

ABSTRACT: Light-woodframe emerges as a modern construction solution to compete with the masonry houses, due to similarities in competitive costs and low-trained labor. This informality contributes to troubles and problems, being identified as perceptible challenges for the building planning and management. A good tool to solve these difficulties consists in the use of a standard checklist during construction process activities, avoiding the negligence of necessary steps to complete the building project. This checklist indicates the systemic view of the complete process, acting as a facilitating and standardizing tool for the progress of on-site building works. To meet these demands, the present paper developed and proposed an organizational tool, materialized by a checklist presented in Appendix section of this paper, in order to monitor the construction process of wood-based houses through light-woodframe system. Due to detailed knowledge of each building phase, this user-friendly checklist adds values and offers organization routines for developers and suppliers. Printed checklists exclude the need of electronic devices on site, allowing copies for all workers. On building site, it allows controlling the systematization and progress of activities, providing a comprehensive systemic view of the work.

Lista de controle de monitoramento para a construção de casas em entramado leve de madeira

RESUMO: O entramado leve em madeira emerge como uma moderna solução construtiva para competir com as casas de alvenaria, devido às similaridades em custos competitivos e na mão-de-obra pouco capacitada. Essa informalidade contribui com os contratempos e problemas, sendo identificada como desafios perceptíveis para o planejamento e a gestão da construção. Uma boa ferramenta para resolver essas dificuldades consiste no uso de uma lista de controle (*checklist*) durante as atividades do processo de construção, evitando a negligencia das etapas necessárias para a conclusão do projeto de construção. Essa lista de controle indica uma visão sistêmica do processo completo, atuando como um facilitador e uma ferramenta de padronização para o progresso dos trabalhos em canteiros de obra. Para atender essas demandas, o presente estudo desenvolveu e propôs uma ferramenta organizacional, materializada pelo *checklist* apresentado na seção de Apêndice deste artigo, a fim de monitorar o processo construtivo de casas de madeira pelo sistema de entramado leve em madeira. Devido ao detalhado conhecimento das fases construtivas, essa lista de controle amigável ao usuário agrega valores e oferece rotina de organização para desenvolvedores e fornecedores. *Checklists* impressos excluem a necessidade de dispositivos eletrônicos no canteiro de obras, permitindo cópias a todos os trabalhadores. No canteiro de obras, permite controlar a sistematização e o progresso das atividades, provendo uma visão sistêmica ampla da obra.

Introduction

Timber-based construction is adaptable to traditional, contemporary and most futuristic styles and limitless possibilities (American Wood Council 2001; De Araujo 2023). Timber houses exceed the concept of no-perennial building in the Northern Hemisphere nations, since they reached high technology and compete with traditional masonry in housing market (Santos and Szücs 2009). However, timber houses are being produced in other regions, insofar as De Araujo and Vasconcelos (2022) have identified an economically perceptible sector aimed at timber houses in Brazil, which has commercially offered dozens of timber construction techniques and systems as verified by De Araujo et al. (2019).

Among the timber construction typologies in architecture, a light-woodframe house stands out as a rational, sustainable and cleaner solution, whose structural lightness and project flexibility are also advantages over other building systems. According to Thallon (2008), compact sizes, flexible varieties in shape and style, easy production with small parts as primary components, simple tools and low skilled labor are the essential reasons which woodframe has been the choice of professional and amateur builders alike over the years.

Despite the use of unskilled workers in civil construction, knowledge and practice in production stages are components capable of refining activities and improving the quality of the works. Strategic tools are needed to guide and standardize activities on building site. According to Novotni et al. (2022), efficient networks connect participants and sectors, which facilitates the exchange of knowledge and information and suggest the way forward.

For this, the present research study developed a checklist with the complete production sequence for a light-woodframe house, in order to facilitate the project monitoring as well as ensure the building execution exactly as planned. Specific objectives aimed to: evaluate the construction sequence of low-rise woodframe housing buildings, define key steps of production process, create a relationship map among their steps, and propose a checklist to monitor and assist the progress of building productions.

Theoretical Background on Light-Woodframe

Molina and Calil Junior (2010, pp. 144) stated a light-woodframe is "durable, structured in treated-wood parts, forming panel of floors, walls and roofs, which are combined and/or covered with other materials, in order to increase the thermal and acoustic comforts, and protecting the building from the weather and fire". Krüger and Laroca (2009) indicated that woodframe uses compact parts based on reforested wood in framing, which is coated with wood-based structural panels. Ergo, De Araujo et al. (2016b) cited that this housing system is a modern way to obtain an industrialized home, despite the possibility of artisanal production on building site.

Thus, woodframe is a predominant method of building homes and apartments in the United States. These houses are economical to build, heat and cool, and provide maximum comfort to users (American Wood Council, 2001).

In 2008, over 90% of all new buildings in North America are made using some version of this method, and remodeling projects are following the same track (Thallon, 2008). Modern conventional woodframe, with wood or wood product materials, is economical, long lasting, and can be built in any location (Anderson, 1975). Woodframe allows up to five-story buildings, with full control over expenses in the project phase due to the possibility of its industrialization (Molina and Calil Junior, 2010).

Due to standardization of the elements/parts prefabrication of a woodframe, De Araujo et al. (2016a) verified that the ease of organization on site and construction cleaning favorably contribute to reduce or eliminate the operational waste.

With any building material or product, solid building and installation practices must be followed to assure durability and trouble-free performance. First approach to achieving a strong and durable structure, involving raw materials savings, follows a basic modular plan for layout and attachment of framing members (American Wood Council, 2001).

Still, light-woodframe system became a new acceptable form of construction for the Brazilian program for social housing development (De Araujo et al., 2019). In contrast, the popularization of this building system in underdeveloped and developing nations may be feasible, since it allows flexible productions from artisanal to full industrialization under part prefabrication based on plantation woods.

Due to several light-woodframe features, the evolution in the utilization of this system could be opportune for scenarios with greater predominance of recent and compact businesses – for example, Brazilian timber housing sector as verified by De Araujo et al. (2018) and economically identified by De Araujo and Vasconcelos (2022).

Theoretical Background on Management

Unlike a production line, which can work indefinitely, projects are processes which require a temporary effort to conclusion. It has beginning, middle and end, in order to produce a manufactured product or service (Project Management Institute Inc., 2004).

Design process is an activity that normally has deficiencies in construction. Thereon, there is the need for multidisciplinary teams, which usually does not exist within the company or, in contrast, they operate without any process management. This fact makes difficult the interaction among design disciplines, and important information about the performance of task is neglected or depreciated (Vivan and Paliari, 2012).

During this construction process for any woodframe house, Kesik and Lio (1997) detailed that there are a number of specific steps and stages, which may be properly planned, coordinated and executed by the manufacturer. A project occurs by a progressive development, i.e., as soon as a step is completed, another step is started, and in the project finishing, the team is untied and relocated to another demand (Project Management Institute Inc. 2004). Thus, a woodframe house project consists of many sub-projects, which has an objective to obtain a building, in shorter terms, with more quality and rational input use.

To a sectoral modernization, Song et al. (2009) stated that the construction industry begins to privilege to the need for integration between the design process and construction activities. In Brazil, as in other countries, the project should present descriptive text, drawings and execution plans, according to the symbology of the Brazilian standard document ABNT NBR-7190 (2022).

Theoretical Background on Checklist to manage and control processes

Guidelines have been efficient tools to assist engineering strategies in civil construction, being present in studies and codes such as Bayless (1986), Longo (1991), Lee et al. (2013), American Society of Civil Engineers (2014), Hegner and Barthel (2015), Tian et al. (2016), among others.

A way to organize the efforts, to share and communicate the key points and to ensure the tasks execution is developed by a standard checklists or verification lists (Gawande, 2009).

In practice, checklist is a sequence of listed and grouped items, which should be checked and/or performed in sequence in order to avoid their neglect or ignorance (Project Management Institute Inc., 2004). This tool can control the routine processes.

A construction process checklist for light-woodframe system should address all key points of the project to facilitate and clarify the work monitoring and management, and ensure the project about expectations in budget and time.

Gawande (2009) stated that the "checklist is the information tool used to reduce errors caused by human limitation of memory and attention, helping to ensure greater consistency and tasks fulfillment, i.e., it lists what should be executed.". It plans the necessary actions. A checklist shall provide a listing with small check box at the left of the task, and a mark in this box should be done only when the task is done (Project Management Institute Inc., 2004).

Theoretical Background on PDCA-cycle and Phenomena Analysis

Stratification is data classification process into subgroups based on features or categories, dividing information into groups (Campos, 1994). Production stratification implies in an important step for mapping situations and attributes related to each other, and distinguishing production phases. Thus, PDCA (plan-do-check-act) consists in a cycle to manage and improve production processes.

As a helpful procedure to follow, Deming (2000) prescribed that PDCA-cycle involves four different stages, to:

- Identify and analyze the problem;
- Create and test a potential solution;
- Check how effective the test solution was and analyze if it could be improved;
- Implement the refined solution.

In P-step, plan, phenomena analysis is highlighted, that is, the characterization of the identified problems, or, the process analysis to discover the causes of problems and action plan for the problem solution (Campos, 1994). Table 1 shows its main tools and respective functions.

Table 1. Tools for problem identification and phenomena analysis. Source: Campos (1994).

Tool	Function
Stratification	Data classification process into subgroups based on categories or characteristics, dividing the information into groups
Pareto chart	Bars and lines graph to order occurrences frequency, allowing problem prioritization, showing cumulative percentage curves
Relationship map	Shows the interrelationship between the processes with the outside environment, showing the project horizontal view
Scope diagram and process interface	Verify each input and which interfaces are responsible for outputs, whose analyses include description designs

Material and Methods

This research was carried out by first author, under main supervision of last author, with formal assistance and simultaneous supervisions of other co-authors, since a relevant volume of specific information was considered.

Initially, literature prospections were carried out to understand production process of a light-woodframe system, plan-do-check-act cycle, and phenomena analysis with problem recognition.

Tools detailed in Table 1 were followed with respect to each route suggested by Campos (1994).

The present study considered the main actors involved in light-woodframe production through a stakeholder analysis to support environments from domestic perspectives – with similar initiative to Gültekin (2018), Pelyukh and Paletto (2019), and others. The processes and activities were identified from authors' experiences and literature contents.

By the PDCA cycle, woodframe production was analyzed with attention to construction process phenomena as well as verify its working and respective steps. Here, macro and micro-steps of each phase were clearly defined and detailed. After that, it was built a relationship map of the processes, applying a systemic view of the process and detailing each phase. It also was verified the requirements to ensure that each step can operate as planned, fulfilling its function. For this analysis, "scope diagram and process interface" was used under the respective functions mentioned by Table 1. In this phase, concepts and routes detailed by Campos (1994) were followed. Inputs and outputs were defined for each macro-step – indicated by the previous analysis – and the interfaces responsible for each one.

This analysis ended with definition of whole sequence and the needs of woodframe construction process. With these analysis tools, process critical steps and input needs of them were defined, allowing the preparation of a monitoring checklist for a woodframe house – indicated in the Appendix. Such checklist should be used for the professionals involved on construction site know about the demands, needs, next steps, consequences of their work, and the performance for the building. This phase agrees with the strategies proposed by Project Management Institute Inc. (2004) for checklists. Information and suggestion shared by Longo (1991) were also regarded to develop this final phase.

Results

Stratification of Production Micro/Macro Steps for Light-Woodframe Houses

Construction processes and micro and macro steps were listed by authors' experience on light-woodframe buildings. Some resources and entries were confirmed from literature such as information from wooden parts and processes on walls flooring and roofing, which were also detailed by Anderson (1975), Kesik and Lio (1997), American Wood Council (2001), Kruger and Laroca (2009), and De Araujo et al. (2016a).

In practice, a light-woodframe house can be divided in four macro-steps: foundation; walls, flooring and roofing; supplies; and finishing. All the macro-steps were correlated with a previous macro-step, which encompasses all the plans, drawings and detailing; this part was given by planning phase. Each macro-step contains multiple micro-steps.

By decoupling of these analyzed steps with a stratification tool detailed by Table 1, a sequence of every basic step was designed for light-woodframe houses (Fig. 1). Macro-steps (vertically oriented) and respective micro-steps (horizontally oriented) were defined in this construction stratification for works using light-woodframe building system.

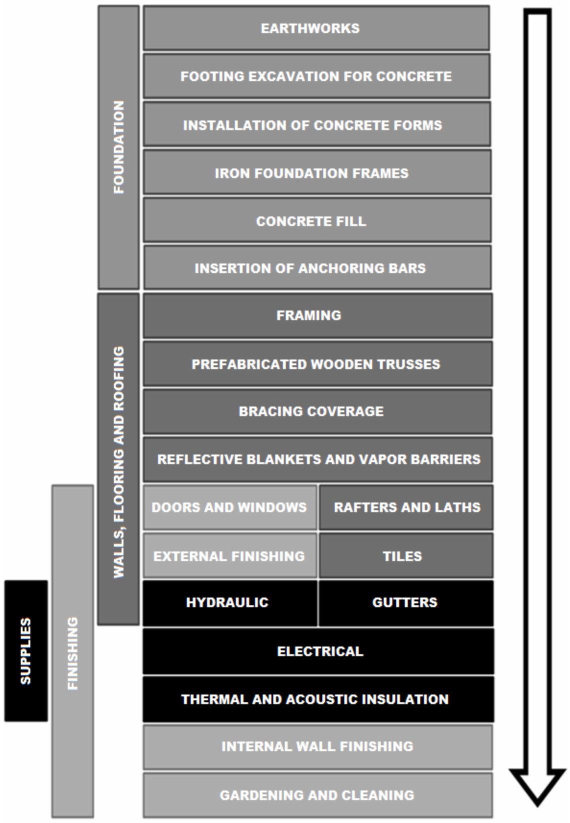

Figure 1. Sequence of the construction processes proposed by authors for light-woodframe houses.

Relationship Map for Light-Woodframe Houses

From definition of production sequence (Fig. 1), the focus aimed to ensure a systemic view of the process and respective links. Thus, the project relationships were verified, including construction, clients, suppliers, regulators, and those relationships among each step and sub-step of the process. For this, it was used the functional analysis of PDCA cycle and the tool of relationship map.

Parallelism of steps occurs only in the end of the process, since steps are not independent, but they are obligatory for the construction sequence. Relationship map of platform woodframe (Fig. 2) was obtained for a two-story house.

In addition, some considerations of building process were made with respect to the excavation activity (included as earthworks micro-step in the foundation macro-step), and prefabricated trusses (included as a micro-step). Both activities/products can be fully or partially developed by third-party woodworking partners.

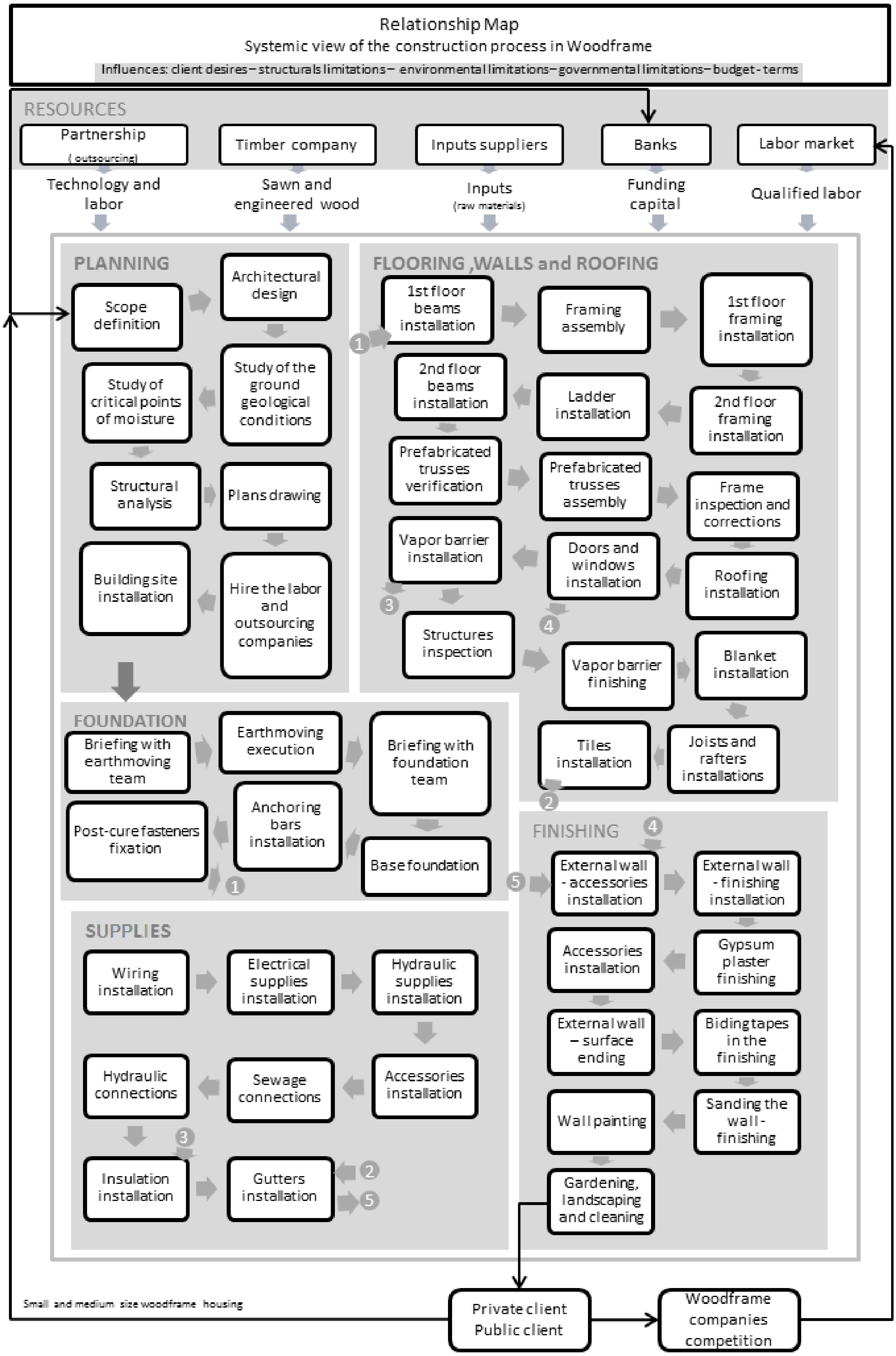

Figure 2. Relationship map proposed by authors for light-woodframe houses.

Scope Diagram and Process Interface for Light-Woodframe Houses

After relationship map (Fig. 2), a functional analysis phase was also concluded, enabling the execution of phenomena analysis of PDCA.

Then, a scope diagram and process interface tool and Pareto graph were utilized. From analyses, the obtained information and results were detailed in Table 2 for specific interface and responsibilities and in Figure 3 for specific inputs.

Table 2. Inputs by interface.

Interface	Responsible Inputs	Inputs Backlog	Responsibility
Designer	21	23.1%	Project drawings, plans, detailing and computer drawings.
Engineering team	14	15.4%	Scale structures, monitor performance, quantify materials and solve problems.
Inputs suppliers	10	11.0%	Provide all the raw materials as requested in the house project.
Architecture team	8	8.8%	Illustrate and design the building and detailing as the client request.
Framing team (carpentry)	6	6.6%	Know wood material, understand plans and details and build the framing.
Foundation company	5	5.5%	Assist in the foundation design, and build the foundation as planned.
Timber company	4	4.4%	Supply wood as the requested quality and quantity, and on schedule.
Client	3	3.3%	Explain the wishes and desires and provide the funding capital.
Prefab trusses company	1	1.1%	Assist the roofing design and to build prefabricated wood trusses as planned.
Finishing team	1	1.1%	Realize internal and external finishing with perfection and without failures.
Gutter team	1	1.1%	Install gutters to collect rainwater, eliminating the moisture in framing.
Electrical team	1	1.1%	Install the electrical wiring to provide safely the energy distribution.
Hydraulic team	1	1.1%	Install the water supply to provide safely the water and sewage services.
Insulation team	1	1.1%	Install the thermal and acoustic insulations within walls, roofs and floors.

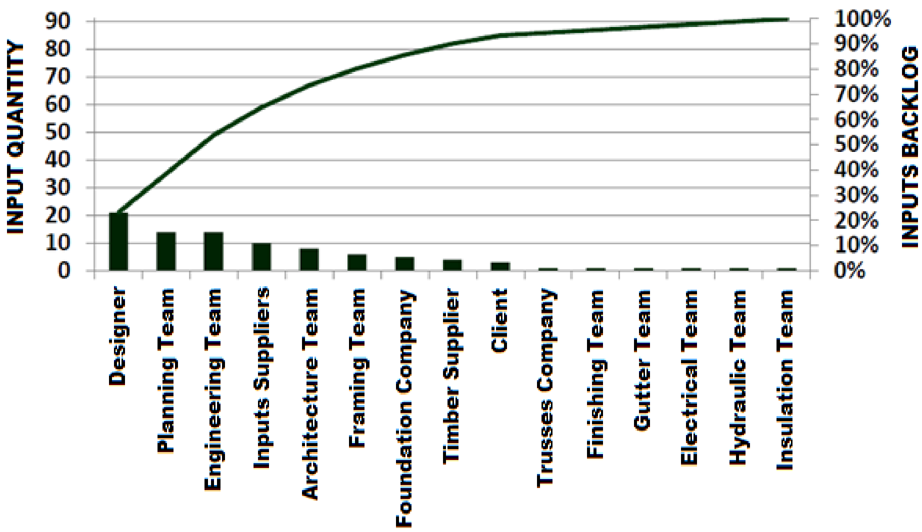

Figure 3. Pareto graph regarding the responsibilities of the building interfaces.

At this stage, the diagnosis process was obtained, evaluating input/output qualities. If an input is not conforming, probably there will be an impact in the outputs. If all inputs are conforming and, even then, there are not conforming outputs, the problems are evidenced in the process. This tool was used to evaluate which interfaces must be controlled to ensure good results in the process.

Six diagrams were performed for each step of the construction process, based on the clusters identified in the relationship map. Individually, these diagrams reflect each macro process and they are used for the analysis of the overall construction process. After the scope diagrams and process interface tool, the responsible inputs were identified and quantified in each interface (Table 2), regardless of the repeat of inputs for other process.

From Table 2 data, a Pareto graph was duly plotted, defining which interfaces with greater responsibility (Fig. 3). The largest number of inputs is set in the initial steps, for the most part under the responsibility of qualified teams.

Proposition of a Monitoring Checklist for Low-rise Light-Woodframe Houses

With the analyzed information detailed in previous sections, a checklist for monitoring of the construction process of low-rise woodframe houses was defined and described, which aims to control every input of the construction process and ensure the quality of all inputs, and hence, of all outputs.

The monitoring checklist was proposed for a light-woodframe production process, that is, with a short and medium housing production. For more elaborate buildings, this checklist could and should be increased to control the execution of activities with more accuracy. Basic and common steps for all woodframes sizes (small to large) are in the scope of the checklist proposal (See Appendix). Any building manager can use checklist as a tool for building monitoring and progress, which can be predicted delays and/or quality problems, and consequently, cost savings. This checklist must be constantly reviewed and suited to the characteristics of each project. Further entries are able to be completed in the checklist, or even, inserted as new steps to consider domestic laws and codes.

Discussions

Individual steps are sequential, but that does not impede their relocation or their simultaneous conduction, as some of these steps are dynamic. In the production sequence (Fig. 1), some steps cannot be changed or simultaneously performed such as: six micro-steps that compose foundation macro-step, and the micro-steps of framing, trusses and bracing coverage. These phases are the main steps for the project ending with a good level of quality and structural safety. To the beginning of the following steps these processes must be finalized.

Through the relationship map analysis, it can be defined which is the dependence of each step of the process. The organization, or chief-engineer, responsible for the construction has the obligation to yield a light-woodframe house within the client requests, without modifications in the terms and costs. The client is obligated to get the total capital that will be used for the material purchasing and payment of all the costs and profits of the organization responsible of works.

During the planning step, the client needs to define the housing aspects, according to its needs and wishes. In addition, the client must always be available to the architect and engineer for proper explanation and clarification of possible questions about the project. After agreeing on what will be built by the responsible organization, the client must validate the design, detailing and drawings in each phase during construction planning. Therefore, the client has the obligation to check the progress of the building periodically, to track its status.

Partner companies must deliver products and their services requested by chief-engineer, since this manager has the technological resources and skilled labor for the performance of activities. These deliveries must be clarified during the planning and hiring of the service. Project planning should be done in conjunction with partnership, via outsourcing, or at least, involving them in the planning of deliveries which they will have authority and responsibility. Timber companies are the main suppliers of wood-based inputs, especially lumber. This raw material should be delivered in different requested dimensions, quality and quantity, in accordance with the packing list of the project. In addition, the wooden parts requested with chemical treatments (against wood decay or fire), they should be clearly identified to the other parts. All wooden materials must have a controlled humidity, and must be available on site with moisture contents close to the equilibrium with the relative humidity of the ground location. Other construction suppliers are responsible for the supply of wooden boards, plaster, tiles, thermal and acoustic insulation, vapor barrier blankets, bath ware, wiring, pipes, and others. All materials must be delivered in accordance with the requested, that is, in the term, quantity, and quality. It should be noted that delays in any font of resource or service will result in the delay of the construction ending, as well as the quality of the products could cause the absence of the quality of the building.

Early deliveries could result in a problem of storage plans, allocating the materials to improper spaces, and exposing them to damages. It could cause more production costs with new purchases and also generate more waste. The monitoring checklist is designed to facilitate the control and management of the construction for the involved actors in the production of low-rise light-woodframe housing buildings (See Appendix).

More tools for monitoring can be used as a complement such as action plans, Gantt charts, and project monitoring software and graphics. Ramani and Kannan (2014) confirmed that project network techniques for planning and scheduling activities are strategic tools for construction management, including critical path method (CPM), program evaluation and review (PERT), graphic evaluation and review (GERT), and others. According to these authors, GERT/PERT/CPM tools are simple yet operative methods for reducing delays and saving costs in construction, insofar as they can optimize the work flow and assess all delay factors in the construction activities.

In practice, these alternative tools are good complements to the proposed checklist so that the construction management can be more predictable, feasible, and efficient in cost and time terms.

In contrast, most of these construction tools require the use of electronic devices as well as they require higher task level. The building monitoring through this checklist can offer organization and practicality, by presenting a very quick and easy fill interface. Thus, this proposed tool is accessible to everyone in the construction, since it does not require preparatory courses for its efficient use. The simple interface with free access and replication to any interested professional makes this structured tool on elementary and efficient ways, avoiding the use on building site of notebooks, mobiles, and/or tablets. The use starts with printing the checklist in paper sheets (e.g. A4-size), which are filled along building progress. Anyone can fill paper sheets with marks performed in the check boxes located in the left of each micro-step, allowing controlling every finished activity, current status, and next demand.

Conclusion

Due to low level education from most work teams from Brazil and other developing nations, there is the essential need to create simple and agile tools to achieve similar efficiency to fully modern technological alternatives, and the checklist (detailed in the Appendix) was efficiently developed as a tool to control the organization and management of each building phase of low-rise light-woodframe houses.

While construction workers hardly have access to training, this user-friendly checklist offers considerable value and organization for all developers and suppliers with a comprehensive systemic view. Systematization and progress of activities are controlled by paper sheets, excluding the use of electronic devices and spreadsheets.

The monitoring checklist allowed managing and controlling the numerous tasks of the complex production of light-woodframe, since this building system demands an intense organizational rhythm and detailed logistics with responsible professionals and multiple input quantities and backlogs.

References

ABNT (2022) *NBR 7190: Projeto de estruturas de madeira*. Rio de Janeiro: ABNT.

American Society of Civil Engineers (2014) *Guideline for condition assessment of the building envelope*. Reston: ASCE.

American Wood Council (2001) *Details for conventional wood frame construction*. Volume 1, Washington: AF&PA.

Anderson LO (1975) *Wood-frame house construction*. n. 73, Madison: FPL.

Bayless RP (1986) Contractor's quality control and owner's guidelines. *Journal of Professional Issues in Engineering Education and Practice* 112(4):230-235.

Calil Júnior C, Dias A (1997) Utilização da madeira em construções rurais. *Agriambi* 1(1):71-77.

Campos VF (1994) *Gerenciamento da rotina do trabalho do dia-a-dia*. Belo Horizonte: INDG.

De Araujo V (2023) Timber construction as a multiple valuable sustainable alternative: main characteristics, challenge remarks and affirmative actions. *International Journal of Construction Management* 23(8):1334-1343.

De Araujo V, De Araujo F, Gava M, Garcia J (2019) Funding modalities for timber housing in Brazil. *Acta Silvatica Lignaria Hungarica* 15(1):35-45.

De Araujo V, Nogueira C, Savi A, Sorrentino M, Morales E, Cortez-Barbosa J, Gava M, Garcia J (2018) Economic and labor sizes from the Brazilian timber housing production sector. *Acta Silvatica Lignaria Hungarica* 14(2):95-106.

De Araujo VA, Cortez-Barbosa J, Garcia JN, Gava M, Laroca C, César SF (2016a) Woodframe: light framing houses for developing countries. *Revista de la Construcción* 15(2):78-87.

De Araujo VA, Cortez-Barbosa J, Gava M, Garcia JN, Souza AJD, Savi AF, Morales EAM, Molina JC, Vasconcelos JS, Christoforo AL, Lahr FAR (2016b) Classification of wooden housing building systems. *BioResources* 11(3):7889-7901.

De Araujo VA, Gutiérrez-Aguilar CM, Cortez-Barbosa J, Gava M, Garcia JN (2019) Disponibilidad de las técnicas constructivas de habitación en madera, en Brasil. *Revista de Arquitectura* 21(1):68-75.

De Araujo VA, Vasconcelos JS (2022) Timber housing economy in Brazil: 2013 to 2022 scenarios and crises. *Advances in Forestry Science* 9(1):1693-1700.

Deming WE (2000) *Out of the crisis*. Cambridge: MIT Press.

Ferreira R (2013) MCMV da madeira: conheça a tecnologia e os custos de construção do primeiro empreendimento em wood frame do programa minha casa minha vida. *Guia da Construção* 66(146):16-25.

Garay RM, Figueroa W, Pfenniger F, Tapia R, Larenas J (2017) Project shelter, part 1: fire resistance and thermal insulation. *Revista de la Construcción* 16(2):339-354.

Gawande A (2009) *Checklist manifesto - how to get things right*. New York: Metropolitan Books.

Gültekin YS (2018) Stakeholder analysis and stakeholder management: a conceptual framework for Turkish forestry. *International Journal of Humanities and Cultural Studies* 5(3):142-157.

Hegner HD, Barthel R (2015) *Guideline accessibility in building design*. Berlin: Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety.

Kesik TJ, Lio M (1997) *Canadian wood-frame house construction*. Ottawa: Canada Mortgage and Housing Corporation.

Kruger EL, Laroca C (2009) Avaliação de desempenho térmico de protótipo de baixo custo em madeira de reflorestamento. *Revista Escola de Minas* 62(4):447-454.

Lee N, Dossick CS, Foley SP (2013) Guideline for building information modeling in construction engineering and management education. *Journal of Professional Issues in Engineering Education and Practice* 139(4):266-274.

Longo PM (1991) Development of in house project evaluation checklist. *Journal of Management in Engineering* 7(2):153-166.

Molina JC, Calil Junior C (2010) Sistema construtivo em wood frame para casas de madeira. *Semina* 31(2):143-156.

Novotni A, Pásztory Z, Tóth Z (2022) Social network analysis in wood industry projects. *Acta Silvatica Lignaria Hungarica* 18(2):89-101.

Pelyukh O, Paletto A (2019) Stakeholder analysis to support secondary Norway spruce (*Picea abies* (L.) Karst.) forest conversion in the Ukrainian Carpathians. *Acta Silvatica Lignaria Hungarica* 15(2):69-84.

Pfeil W, Pfeil M (2003) *Estruturas de madeira*. Rio de Janeiro: LTC.

Powell KL, Tilotta DC, Martinson KL (2008). *Assessment of research and technology transfer needs for wood-frame housing*. Madison: USDA.

Project Management Institute Inc. (2004). *Um guia do conjunto de conhecimentos em gerenciamento de projetos (Guia PMBOK®)*. 3rd Edition. Newtown Square: PMI Inc.

Ramani T, Kannan R (2014) Scheduling of industrialized construction project using graphical evaluation and review technique (GERT). In: 2014 Proceedings of second International Conference on Advances in Industrial Engineering Applications, Anna University, Chennai, India.

Santos AC, Szücs CA (2009) Sistema estrutural de piso em madeira composto de chapas de OSB e vigas I. *Ambiente Construído* 9(3):75-93.

Song L, Mohamed Y, Abourizk SM (2009) Early contractor involvement in design and its impact on construction schedule performance. *Journal of Management in Engineering* 25(1):12-20.

Szücs CP (2004) Sistema Stella-UFSC: avaliação e desenvolvimento de sistema construtivo em madeira de reflorestamento voltado para programas de habitação social. Florianópolis: UFSC.

Thallon R (2008) *Graphic guide to frame construction*. Newtown: Taunton Press.

Tian J, Symans MD, Pang W, Ziaei E, van de Lindt JW (2016) Application of energy dissipation devices for seismic protection of soft-story wood-frame buildings in accordance with FEMA guidelines. *Journal of Structural Engineering* 142(4): E4015009.

Vivan AL, Paliari JC (2009) Design For Assembly aplicado ao projeto de habitações em light steel frame. *Ambiente Construído* 12(4):101-115.

Appendix

Checklist for low-rise light-woodframe housing buildings.

MACRO-STEP 1: PLANNING			
Step / Status	**Action**	**Responsible**	**Former Step**
1.1 ( )	Define the limit of the budget and to get the amount to pay for all the construction.	Client	–
1.2 ( )	Present the ground for the construction.	Client	–
1.3 ( )	Detail the ground dimensions.	Engineering team	1.2
1.4 ( )	Define the building design and the house characteristics.	Client	–
1.5 ( )	Define ground characteristics (brightness, wind, noise, traffic, temperature, etc.).	Engineering team	1.2
1.6 ( )	Create the architectural design sketch.	Architecture team	1.1 / 1.3 / 1.4 / 1.5
1.7 ( )	Validate the plan sketch with the engineering team and the client.	Architecture team	1.6
1.8 ( )	Create the architectural design.	Architecture team	1.7
1.9 ( )	Create the 3D-model of the architectural design.	Architecture team	1.8
1.10 ( )	Validate the architectural design with the engineering team and the client.	Designer	1.9
1.11 ( )	Realize the study of the ground soil.	Engineering team	1.3
1.12 ( )	Define necessary soil changes.	Engineering team	1.10 / 1.11
1.13 ( )	Realize the structural design according to the Brazilian standard NBR7190/2022.	Engineering team	1.10 / 1.12
1.14 ( )	Draw the floor plan.	Designer	1.13
1.15 ( )	Draw the detailed plans of the floorings.	Designer	1.13
1.16 ( )	Draw the detailed plans of the walls.	Designer	1.13
1.17 ( )	Draw the detailed plans of the roofing.	Designer	1.13
1.18 ( )	Draw the detailed plans of the electric system (wiring).	Designer	1.13
1.19 ( )	Draw the detailed plans of the hydraulic system (plumbing) and sewage system.	Designer	1.13
1.20 ( )	Draw the detailed plans of the internal and external finishing.	Designer	1.13
1.21 ( )	Quantify all the necessary materials and inputs for the project.	Engineering team	1.13
1.22 ( )	Quantify the need of man-hours for each stage of the project.	Engineering team	1.13
1.23 ( )	Define the working teams by each stage (framing, electrical, hydraulic, finishing, etc.).	Planning team	1.13
1.24 ( )	Hire the foundation company and the company of prefabricated trusses.	Planning team	1.13
1.25 ( )	Validate designs with teams (engineering, architecture, working) and subcontractors.	Designer	1.14 to 1.20 / 1.23 / 1.24
1.26 ( )	Define the construction schedule.	Planning team	1.22 / 1.23 / 1.24
1.27 ( )	Validate the schedule with subcontractors, and teams of engineering and working.	Planning team	1.26
1.28 ( )	Define the delivery schedule of the materials on the construction site.	Planning team	1.22 / 1.23 / 1.24 / 1.27

1.29 ( )	Validate the delivery schedule with the inputs suppliers and engineering team.	Planning team	1.28
1.30 ( )	Provide temporary electric and water supply on the construction site.	Planning team	1.25
1.31 ( )	Provide a storage location of raw materials on the construction site.	Planning team	1.25
1.32 ( )	Provide location for construction workers and for storage of documentation and plans.	Planning team	1.25
1.33 ( )	Disclose all plans, staffs, working/materials schedules, and scopes for client and teams.	Planning team	All the previous stages
1.34 ( )	Provide all the plans and drawings on the construction site.	Planning team	All the previous stages
MACRO-STEP 2: FOUNDATION			
Step / Status	**Action**	**Responsible**	**Former Step**
2.1 ( )	Machinery/tools and workers on the construction site.	Foundation company (subcontractor)	1.33 / 1.34
2.2 ( )	Cleared soil ground (without dirt, rubbish, etc.).	Foundation company (subcontractor)	2.1
2.3 ( )	Cleared soil ground (without trees, stubs, bushes, etc.).	Foundation company (subcontractor)	2.1 / 2.2
2.4 ( )	Realize the ground foundation layout.	Foundation company (subcontractor)	2.3
2.5 ( )	Realize the excavations.	Foundation company (subcontractor)	2.1 / 2.3
2.6 ( )	Background quota as designed.	Foundation company (subcontractor)	2.5
2.7 ( )	Inclination of slopes as designed.	Foundation company (subcontractor)	2.5
2.8 ( )	Ground soil compression.	Foundation company (subcontractor)	2.6 / 2.7
2.9 ( )	Status report of the execution of the earthmoving subcontractor.	Foundation company (subcontractor)	2.8
2.10 ( )	Implementation of the foundation base.	Foundation company (subcontractor)	2.8
2.11 ( )	Insert the iron foundation frames.	Foundation company (subcontractor)	2.10
2.12 ( )	Insert the anchoring bars.	Foundation company (subcontractor)	2.11
2.13 ( )	Installation of concrete forms.	Foundation company (subcontractor)	2.12
2.14 ( )	Fill the forms with concrete delivered by the foundation company or a partner.	Foundation company (subcontractor)	2.13
2.15 ( )	Concrete curing.	Foundation company (subcontractor)	2.14
2.16 ( )	Concrete forms removal.	Foundation company (subcontractor)	2.15
2.17 ( )	Vapor barrier application to the foundation.	Hydraulic team	2.16
2.18 ( )	Drainage pipes installation.	Hydraulic team	2.17
2.19 ( )	Insertion of gravel above the drainage plumbing.	Foundation company (subcontractor)	2.18
2.20 ( )	Foundation re-ground.	Foundation company (subcontractor)	2.19
2.21 ( )	Foundation drilling to fix the post-cure fasteners.	Framing team	2.15
2.22 ( )	Status report of the execution of the foundation company (subcontractor)	Foundation company (subcontractor)	2.20 / 2.21
MACRO-STEP 3: FLOORING, WALLS AND ROOFING			
Step / Status	**Action**	**Responsible**	**Former Step**

3.1 ( )	Ground preparation to receive lumber parts, wooden panels and metal connectors.	Timber company	2.20 / 2.21
3.2 ( )	Receive the sawn wood in the required qualities, quantities and dimensions.	Timber company	3.1
3.3 ( )	Receive the wooden boards in the required qualities, quantities and dimensions.	Timber company	3.1
3.4 ( )	Receive the metal connectors in the required qualities, quantities and dimensions.	Timber company	3.1
3.5 ( )	Positioning of the first-floor beams on the foundation.	Framing team	3.2
3.6 ( )	Installation and connection of the first-floor pieces.	Framing team	3.5
3.7 ( )	Installation of first-floor frames to generate the structural framing.	Framing team	3.6
3.8 ( )	Installation of the coverage of wooden boards fixing them with pneumatic nailers.	Framing team	3.7
3.9 ( )	Truck-crane rental for loading and positioning of frame parts.	Planning team	3.8
3.10 ( )	Positioning of the second-floor beams on the first-floor frames.	Framing team	3.9
3.11 ( )	Installation and connection of the second-floor parts.	Framing team	3.10
3.12 ( )	Installation of ladder structures to connect the first to second floor.	Framing team	3.11
3.13 ( )	Installation of the second-floor frames.	Framing team	3.9 / 3.12
3.14 ( )	Installation of the coverage of wooden boards on the second floor, fixing with pneumatic nailers.	Framing team	3.13
3.15 ( )	Receive the prefabricated wooden trusses in required qualities, quantities and sizes.	Prefabricated truss company (subcontractor)	3.13
3.16 ( )	Installation of the prefabricated wooden trusses above the second-floor frames.	Framing team	3.9 / 3.13 / 3.15
3.17 ( )	Analysis of installed structures to search for failures and flaws, fixing them if necessary.	Framing team	3.16
3.18 ( )	Installation of wooden boards to cover and bracing the framing and roofing.	Framing team	3.9 / 3.16
3.19 ( )	Receive doors and windows in the required qualities, quantities and dimensions.	Inputs suppliers	3.16
3.20 ( )	Installation of doors and windows.	Framing team	3.17
3.21 ( )	Receive the reflective blankets, vapor barriers and their accessories.	Inputs suppliers	3.16
3.22 ( )	Application of vapor barriers across the frame and in windows/doors joints.	Framing team	3.20 / 3.21
3.23 ( )	Application of reflective blankets in the roofing walls.	Framing team	3.20 / 3.21
3.24 ( )	Application of vapor barrier in the roofing walls.	Framing team	3.20 / 3.21
3.25 ( )	Installation of support accessories to installation of tiles.	Framing team	3.9 / 3.18
3.26 ( )	Installation of tiles and coping (ceramic, metal, shingle, or other models).	Framing team	3.9 / 3.18
3.27 ( )	Removal of storage location of raw materials.	Planning team	3.26
MACRO-STEP 4: SUPPLIES			
Step / Status	**Action**	**Responsible**	**Former Step**
4.1 ( )	Receive the electricity supplies.	Inputs suppliers	3.18
4.2 ( )	Receive the hydraulic/sewage supplies	Inputs suppliers	3.18
4.3 ( )	Receive of gutter for roofing materials.	Inputs suppliers	3.18

4.4 ( )	Receive the thermal-acoustic insulation materials.	Inputs suppliers	3.18
4.5 ( )	Drilling passages for wiring conduits (TV, electrical, data and telephone) on frame.	Electrical team	3.18
4.6 ( )	Installation of electrical boxes.	Electrical team	4.1 / 4.5
4.7 ( )	Installation of the wiring (TV, electrical, data and internet).	Electrical team	4.6
4.8 ( )	Installation of light-switches, AC-sockets, junction boxes, connections, etc.	Electrical team	4.6 / 4.7
4.9 ( )	Connection of electrical accessories in the house's electrical wiring.	Electrical team	4.8
4.10 ( )	Provide the electricity with the local utility.	Planning team	4.9
4.11 ( )	Connection of the house's wiring with the local electric power distribution.	Electrical team	4.10
4.12 ( )	Provisional wiring shutdown.	Planning team	4.11
4.13 ( )	Drilling the passages of water pipes and sewers.	Hydraulic team	3.18
4.14 ( )	Installation of sewage boxes and water tanks.	Hydraulic team	4.13 / 4.2
4.15 ( )	Installation of the water pipes and sewers, and their respective valves.	Hydraulic team	4.14
4.16 ( )	Connections of the water pipes with water tanks and the sewers with the sewage boxes.	Hydraulic team	4.14 / 4.15
4.17 ( )	Provide the water and sewage services with the local utility.	Planning team	4.16
4.18 ( )	Connection of the house's plumbing with the water and sewage local utility.	Hydraulic team	4.17
4.19 ( )	Provisional water supply shutdown	Planning team	4.18
4.20 ( )	Installation of thermal-acoustic insulation in gaps of frame studs (walls, floors, trusses).	Insulation team	4.11 / 4.18
4.21 ( )	Installation of the gutters on the roofing structure.	Gutter team	3.18 / 4.3
MACRO-STEP 5: FINISHING			
Step / Status	**Action**	**Responsible**	**Former Step**
5.1 ( )	Installation of the accessories for fixing the internal wall-finishing.	Finishing team	4.11 / 4.18 / 4.20
5.2 ( )	Installation of the accessories for fixing the external wall-finishing.	Finishing team	4.11 / 4.18 / 4.20
5.3 ( )	Installation of internal wall-finishing (gypsum plaster and wood wainscot)	Finishing team	5.1
5.4 ( )	Installation of external wall-finishing (siding, bricks, cement board, plaster, etc.)	Finishing team	5.2
5.5 ( )	Application of biding tapes in the finishing, if necessary.	Finishing team	5.1 / 5.2
5.6 ( )	Application of internal/external finishing (cement or gypsum plaster), if necessary.	Finishing team	5.5
5.7 ( )	Sanding the finishing masses.	Finishing team	5.6
5.8 ( )	Reapplication of finishing masses.	Finishing team	5.7
5.9 ( )	Re-sanding the finishing masses.	Finishing team	5.8
5.10 ( )	Wall painting.	Finishing team	5.9
5.11 ( )	Varnish and stain applications in the external woods, exposed to the weather.	Finishing team	5.9
5.12 ( )	Installation of sinks, toilets, bidets, showers, and bathroom cabinets.	Finishing team	5.10 / 5.11

5.13 ( )	Installation of metal hydraulic fittings (faucets, baths, etc.)	Hydraulic team	5.12
5.14 ( )	Installation of the wall switch plates and lighting (chandeliers and pendants).	Electrical team	5.10 / 5.11
5.15 ( )	Installation of flooring, ceiling panels, and decks.	Finishing team	5.13 / 5.14
5.16 ( )	Installation of baseboards, plasters, moulding, etc.	Finishing team	5.15
5.17 ( )	Gardening and landscaping.	Gardening team	5.16
5.18 ( )	Complete cleaning of the house (internal and externally)	Cleaning team	5.17
5.19 ( )	Thorough scan in the house looking for failures, providing problem solutions.	Engineering team	5.18
5.20 ( )	Final cleaning for the occupation.	Cleaning team	5.19
5.21 ( )	Delivery act of keys for client.	All the teams	5.20