Engineering and management of information modeling requirements

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Highlights

Definition and management of requirements through RsE and RsM methods.
Integration of requirements into the design process through Information Modelling.
Monitoring the quality gap by means of model controls.
Pre-occupancy simulation to evaluate interactions among users.

Abstract

The presented document discusses the application of Requirements Engineering and Management methods and techniques for identification and traceability of requirements to support Information Modelling during the design process. Errors and ambiguities are generally found during the briefing phase. Pre-occupancy simulation on the information model verifies the interactions among future users to meet the intended use. The information model allows to monitor the gap between expected and actual quality throughout the design process.

Keywords

Requirements Engineering and Management, Information Modelling, Pre-occupancy Simulation, Space Programme, Room Data Sheet

1. INTRODUCTION

The requirements are the basis of each project: the final product should meet the needs and requirements expressed by the Client and the Stakeholders. The requirements define the basis for project planning, risk management and monitoring of possible adjustments to the design [1]. They are the main part of the brief phase and of the whole process. During the preliminary stages, the Client provides the actors with information on his needs and requirements: the project has to meet this kind of information [2]. Research reveals a lack of identification, management and traceability of requirements during the design process in the AEC sector [3,4,5,6,7,8].

The need for well-defined requirements and the dynamic nature of the process...
requires the identification of several kinds of requirements. During an empirical survey conducted in 1976, Bell and Thayer stated that incorrect or incomplete definition of requirements is one of the main causes of overcoming time, cost and quality [9]. The authors stated that the requirements for different projects of different fields should be engineered and continuously reviewed [9,10]. An imbalance towards the final stages of the information flow in a traditional process is one of the reasons of the inefficiency of the building process. Indeed, the initial phases of brief and definition of the requirements are critical for the whole process [11]. It is clear that the design teams without any properly defined requirements, methods and monitoring tools are not able to evaluate all the impact of a project change. A solution that meets one requirement could have a negative effect on another crucial goal [10].

In addition, the requirements do not actually support the design process [12], they are not implemented as the design evolves, leading to data loss in the information flow. The high number of changes occurring during the design and the iterative nature of the process increases the complexity of the problem [13]. As a result, changes and decisions are frequently based on the previous version of the design, in order to improve the design solution, without real monitoring of compliance between the design and the initial demands. The design resulting can strongly diverge from the original targets with the impossibility to understand the differences between the design and the client’s goals [13]. (Fig. 1)
In order to reduce ambiguity and inaccuracy in the requirements’ definition, Requirements Engineering (RsE) and Management (RsM) techniques may be applied to the design process. The main purpose of RsE and RsM is to correctly define and simply manage the requirements. Correct application of RsE/M in the AEC sector, as a support to Information Modelling (BIM), can lead to the integration of the requirements into the design process and ensures that the final product meets the customer’s needs.

The work proposes a method of translating the demands into alphanumeric requirements to support the Information Modeling; the method is applied to the design of a primary and secondary school in Posada (NU), on the basis of the Documento Preliminare alla Progettazione (DIP), as a part of Progetto Iscol@, a program of the Region of Sardinia to promote and develop school buildings. The DIP at the basis of the tender was translated into computational requirements. The alphanumeric data supported the decision-making process during the design phase and guided the whole design process. As a result, the BIM methodology allows to link the requirements with the development of the design solution by means of analyses and simulations on the information model. The case study focused on the number of interactions among users in order to ensure the integration of architecture and educational approach, one of the mail goals of Progetto Iscol@. The validation required the use of Pre-Occupancy Simulation.

As a conclusion, the work provides the correct definition and monitoring of requirements by means of RsE and RsM techniques to verify the existing gap between expected and actual. The results of the research show the value of these activities to ensure effectiveness of BIM methodology application and to optimize the design referring to the Client’s goals.

2. METHODOLOGY

The identification of the best design solution requires the evaluation of design alternatives and their comparison. The expression of Client’s demands through a set of measurable, computational and alphanumeric requirements enables the correct evaluation of design alternatives [14]. The building process carried out with BIM methodology is a progressive production and elaboration of data, based on the correct definition of the demand by means of computational requirements or the translation of a traditional demand.

Requirements Engineering (RsE) and Management (RsM) techniques can be applied for this purpose. These methods allow the definition and management of design requirements during the design process: it is possible to record ad un flusso informativo bilanciato verso le fasi finali a sfavore delle fasi iniziali di briefing e definizione dei requisiti, che si sono dimostrate cruciali [11]. Infatti, nel caso in cui non siano stati correttamente definiti requisiti, metodi e strumenti di monitoraggio, i team di progettazione non sono in grado di valutare tutte le ricadute di una modifica proposta. Un può soluzione, che soddisfa un requisito potrebbe avere un effetto negativo su un altro obiettivo fondamentale [10].

Inoltre, i requisiti definiti non sono poi attivamente utilizzati nel processo di progettazione [12] e non sono integrati con l’evolversi della progettazione, causando perdite di dati nel flusso i informativo. Un altro aspetto rilevante è la natura iterativa del processo progettuale, durante il quale il progetto subisce numerose modifiche, aumentando la complessità del sistema [13].

Inoltre, in un processo tradizionale ogni revisione del progetto è confrontata con la revisione precedente, nel tentativo di migliorare progressivamente la soluzione progettuale, senza tuttavia verificare r ispetto a i requisiti iniziali e senza monitorare la rispondenza tra offerta progettuale e domanda. In questo modo, il team di progettazione può perdere di vista gli obiettivi iniziali e la soluzione progettuale può progressivamente discostarsi dai requisiti definiti dalla Committenza [13].

Allo scopo di ridurre ambiguità e imprecisioni nella definizione dei requisiti si possono applicare tecniche di Requirements Engineering (RsE) and Management (RsM). Lo scopo principale di RsE e RsM è definire e facilitarne la gestione. La corretta applicazione nel settore AEC di RsE e RsM a supporto della Modellazione Informativa (BIM) può favorire l’integrazione dei requisiti nel processo progettuale e garantire che il prodotto finale soddisfi le richieste da Committenza.

Il lavoro propone un metodo di traduzione della domanda in requisiti alfamericici a supporto della modellazione informativa; il metodo è applicato al progetto di una scuola elementare e media a Posada (NU), sulla base del bando di progettazione, parte del Progetto Iscol@, un programma della Regione Sardegna per promozione e sviluppo dell’edilizia scolastica. Il Documento di Indirizzo Progettuale (DIP) posto a base di gara è stato tradotto in obiettivi e requisiti computabili.

Le informazioni alfanumeriche sono state utilizzate a supporto del processo decisionale durante la fase metaprogettuale e hanno accompagnato l’intero processo progettuale. La metodologia BIM permette, quindi, di porre in relazione diretta obiettivi e requisiti con l’evolversi della soluzione progettuale, grazie all’esecuzione di controlli, analisi e simulazioni sul modello informativo. Particolare attenzione è stata data alla verifica del numero di interazioni tra gli
and trace the requirements during the design verification cycles. As a result, design changes can be properly managed and the final building performance can be assessed according to the initial requirements. The adoption of RsE and RsM methods allows to generate, compare and verify several design alternatives and to evaluate the impact of design changes on the requirements. It means that it is possible to check the quality of design solutions in terms of compliance with the Client’s requirements. As a result, the selection of the best alternative is based on a structured and defined method, minimising the uncertainty and risks associated to the decision-making process.

**Decision Support System**

The method adopted to structure the demands can be considered as a Decision Support System (DSS) for the Client. DSSs allow to define the best alternative that meets the initial requirements through an optimization process [15,16,17,18]. The correct definition of the DSS requires to express goals and requests by means of RsE and RsM, as previously mentioned. In the current case study, the strategic aims representing the Client’s needs were identified on the basis of the DIP analysis. The strategic goals were then translated into specific targets and alphanumeric requirements. In many cases the DIP includes considerations and information on the aesthetic quality of spaces: a primary issue is the translation of quality requirements into computational requirements, as discussed below.

**Requirements Engineering: Kansei Engineering and Analytic Hierarchy Process**

Traditionally, it is possible to translate qualitative verbal expressions into computational and numerical values, according to the Quality Function Deployment (QFD) method. In a traditional approach, the same actors who expressed a qualitative evaluation on a product’s feature translate the expression into a numerical value. Qualitative verbal expressions such as “good”, “medium” or “not sufficient” is translated into a number through the Likert value scale [14].

Referring to the case study, the demands expressed in the DIP are the basis of the tender and therefore cannot be modified. As a consequence, a methodology based on Kansei Engineering [19] was used to define the requirements and sub-requisites. This method developed in Japan allows to translate the quality requirements the customer expresses into quantitative attributes of a product [20]. As a result, this approach ensures a higher quality of the product, designed according to the end-user’s targets.
The method adopted focuses on the analysis of the DIP to identify the strategic goals, unable to be expressed in alphanumeric terms. The increasing level of detail of the strategic goals made it possible to define measurable targets to express the Client’s needs. These targets are defined specific targets, as shown in the flow in Figure 2.

The specific goals have the following features: Specific, Measurable, Achievable, Realistic, Time-related; moreover, they allow the unambiguous evaluation of design alternatives through numerical values and computational requirements.

Once the system was structured, a multi-criteria analysis made it possible to evaluate the alternatives according to the identified goals. During this phase, conflicts may arise among different and contrasting targets. The Analytic Hierarchy Process (AHP) method, a kind of multi-criteria analysis, allows to introduce a hierarchy among the several alternatives and to solve possible conflicts [21]. The AHP method enables the assignment of weights to the specific targets, creating a hierarchy of targets. The method to assign weights to the specific targets was the verification of how many times a specific target, or the related strategic goal, was mentioned in the DIP, as a Client’s need or indication [22]. This way, each design alternative gets a score. Weights are then assigned to the scores according to the related specific targets’ weights, thus allowing a numerical matching of the design solutions.

Space programme and Room Data Sheet

The requirements defined and structured by means of RsE and RsM were then collected and categorized in the Space Programme’s design document, according to related specific targets and spatial units. BIM methodology provides digital data containers defined Room Data Sheets (RDS) to collect and manage the defined requirements. The information integrated into the RDSs creates a direct link between the Client’s requirements, the design method and the information model. As a result, the management and traceability of requirements and the monitoring of the design process evolution are facilitated.
Moreover, the Information Modeling allows to gather in a single database, i.e. the information model, the data for the definition of the design concepts; consequently, data and constraints provided by the Client, regulations and context are no longer a subsequent verification, rather than a support to the definition of the design solution. As a result, it anticipates the encounter/clash between the creative process and the checks and analyses necessary to correctly define the design.

**Pre-occupancy Simulations to verify interactions among users**

The evaluation of some of the requirements implies the use of simulations to get a numerical value for each design alternative. The application of Pre-occupancy Simulations enabled the numerical verification of the interactions among users in the designed spaces. This was a key parameter in order to meet one of the main goals of the process, namely the integration of architecture and educational approach.

Pre-occupancy simulations are based on Crowd Simulation systems. Crowd Simulation systems are computerized analyses of the movement of crowds and are generally used for emergency simulations [23,24,25]: in the case study, the simulation reproduces the actual use of spaces, in order to verify the spatial quality of the designed spaces. Spatial quality is defined as the ability of spaces to meet the intended use.

There are two types of Pre-occupancy Simulation: Agent-based and Narrative driven, described below. Microscopic Agent-based simulations are the ones used in the current case study: the users maintain their own peculiarities and the ability to act independently, while at the same time their behaviour influences choices and movements of nearby occupants [26]. There is, therefore, an effect of individualisation of the movement of crowds [27]. The user reacts to simple motion rules (K.I.S.S.) [28] and a widespread A.I. (Artificial Intelligence) drives its actions and ensures randomness of movements in space [27]. Pure Agent-based simulation has a limitation: it is possible to populate the model of a building; however, the movement of the occupants is extremely chaotic [29].

As a consequence, it is necessary to apply a second type of simulation, defined Narrative Driven, which formalizes the sequence of activities the user carries out. A Narrative Driven simulation also presents some limits: the need to formalize every single activity carried out inside the spaces causes a strong rigidity. As a result, the analysis appears more as an animation than as a simulation.

The adopted solution involves the mixed use of the two systems, thus removing...
the above limitations. This kind of simulation is not currently implemented in a traditional design process, resulting in lower quality of the design solution [29].

3. ANALYSES AND RESULTS OF THE CASE STUDY

The above methodology was applied to the case study of the design of a primary and secondary school in Posada. During the preliminary stages, data, constraints and requirements resulting from the DIP supported the definition of the design alternatives. This method allowed the accurate check for compliance of the alternatives with the Client’s needs. The translation of the DIP into computational requirements required in the initial phase a relevant amount of time: 14 strategic goals, the related 36 specific targets and 25 spatial requirements were identified and assigned to the Room Data Sheets, relating to each space. According to the methodology above, weights are then assigned to each specific target.

The evaluation of design alternatives in preliminary stages referring to the measurable requirements allowed to get advanced design concepts. Each alternative is linked to a weighted score according to the demands. As a result, during the concept phase needs and constraints guided the design changes. Information Modeling enabled also to carry out analyses and simulations to verify the requirements since the preliminary design phase. This operation is complex or excessively expensive in a traditional approach.

As mentioned above, a mixed approach based on Agent-based and Narrative Driven simulations was checked and allowed to measure the spatial quality. The model used is unable to replicate and simulate all aspects of human behavior; it provides just predictive data on number and quality of interactions among users in spaces. The proposed model allows, therefore, to quantify, verify and evaluate the spatial configurations, according to the spatial quality, defined as the number and variety of interactions, as well as the personal comfort of each user by reducing the crowding phenomena [22].

Simulations on the information model increased the comprehension of the design and the effectiveness of the Customer-designer communication. It is also possible to anticipate the effects of the future occupants’ use of the building and their interactions [30], resulting in changes of designed spaces features.

Simulations identified issues related to the management of spaces, as well as the need to review some aspects of the common spaces’ design. The outputs of the Pre-occupancy Simulation software are frequency and density maps showing crowding data at any point in the space (Fig. 3).
The data collected are useful to identify the main flows and define space occupation index, allowing the evaluation of size and ability of the spaces to meet the future users’ needs. Simulation results highlighted the need to increase the number of exits: it enabled to reduce the intensity of entry and exit flows. Moreover, the simulation showed the need to review design and features of the stairs connecting the school levels, in order to avoid dangerous situations of overcrowding. The most remarkable aspect of these results is that spaces and elements modified were already sized according to the regulations. As a result, the analyses revealed issues associated to the actual use of the designed school and related to the complexity of the planned users’ flows.

4. CONCLUSIONS

The case study highlighted the advantages of applying the proposed methodology. The use of RsE and RsM techniques and simulations to support the Information Modeling method allowed to identify, manage and trace the requirements while integrating them in the design process. The information model, by means of analyses and simulations, ensured the monitoring of the design alternatives and the check for compliance with the Client’s needs. The various stakeholders became aware of the impact of the changes, thanks to the clear, defined and well-structured requirements. Future development includes the possible connection of the information model to automatic Business Intelligence systems: these systems can be used
to manage and show performance indices related to the design process. As a result, data collected from several analyses can be visualized in real-time: subjects responsible of the decision-making process and unaware of modelling processes can decide on currently up-to-date data and performance diagrams related to the design.

5. REFERENCES

[25] Tang, F.; Ren, A., Agent-Based Evacuation Model Incorporating Fire Scene and Building proposte, in funzione della qualità spaziale, definita e ome numerosità ed etereogenità delle interazioni, nonché del comfort personale del singolo utente tramite la riduzione dei fenomeni di affollamento [22]. Le simulazioni sul modello informativo hanno consentito un aumento della comprensione del progetto, dell’efficacia della comunicazione Commitmente-progettista e della capacità di anticipare gli effetti dell’uso dell’edificio a par di futuri utenti e le loro interazioni [30], modificando i c e conseguenza le caratteristiche degli spazi in progetto (Fig. 3). Le simulazioni hanno messo in luce problematiche relative alla gestione degli spazi in progetto, nonché la necessità di rivedere alcuni aspetti progettuali degli spazi comuni della scuola. Il software utilizzato per le Pre-occupancy Simulation permette di estrarre mappe di frequenza e densità contenenti i dati relativi all’affollamento in ogni punto dello spazio. I dati sono utili all’identificazione dei principali flussi e definire l’indice di occupazione degli spazi, permettendo una valutazione sul dimensionamento e sulla capacità degli ambienti di accogliere le attività dei futuri utenti. L’analisi dei risultati della simulazione ha evidenziato, ad esempio, la necessità di aumentare il numero di uscite previste, riducendo l’intensità dei flussi in e ne ritratta e uscita. Sono stati, inoltre, rivisti i dimensionamenti delle scale di collegamento tra i piani della scuola, per evitare situazioni pericolose di affollamento eccessivo. L’aspetto rilevante di questi risultati è che gli ambienti ed elementi modificati grazie alle simulazioni erano già stati correttamente dimensionati secondo i limiti normativi. Di conseguenza, le analisi hanno anticipato problematiche date dalla complessità dei flussi di utenti previsti e che, altrimenti, si sarebbero presentate solo una volta che la scuola fosse occupata.

4. CONCLUSIONI
Il caso studio analizzato ha evidenziato i vantaggi dell’applicazione della metodologia proposta. L’uso di ReE, ReM e simulazioni a supporto della modellazione informativa ha permesso di individuare, gestire e tracciare i requisiti integrandoli in conseguenza le simulazioni a supporto della proposta. L’uso di RsE, RsM e simulazioni a supporto della modellazione informativa ha permesso di individuare, gestire e tracciare i requisiti integrandoli in conseguenza le simulazioni a supporto della proposta. L’uso di RsE, RsM e simulazioni a supporto della modellazione informativa ha permesso di individuare, gestire e tracciare i requisiti integrandoli in conseguenza le simulazioni a supporto della proposta. L’uso di RsE, RsM e simulazioni a supporto della modellazione informativa ha permesso di individuare, gestire e tracciare i requisiti integrandoli in conseguenza le simulazioni a supporto della proposta. L’uso di RsE, RsM e simulazioni a supporto della modellazione informativa ha permesso di individuare, gestire e tracciare i requisiti integrandoli in conseguenza le simulazioni a supporto della proposta. L’uso di RsE, RsM e simulazioni a supporto della modellazione informativa ha permesso di individuare, gestire e tracciare i requisiti integrandoli in conseguenza le simulazioni a supporto della proposta. L’uso di RsE, RsM e simulazioni a supporto della modellazione informativa ha permesso di individuare, gestire e tracciare i requisiti integrandoli in conseguenza le simulazioni a supporto della proposta. L’uso di RsE, RsM e simulazioni a supporto della modellazione informativa ha permesso di individuare, gestire e tracciare i requisiti integrandoli in conseguenza le simulazioni a supporto della proposta. L’uso di RsE, RsM e simulazioni a supporto della modellazione informativa ha permesso di individuare, gestire e tracciare i requisiti integrandoli in conseguenza le simulazioni a supporto della proposta. L’uso di RsE, RsM e simulazioni a supporto della


