Determining the Degree of Reliability of Energy Simulation Based on a Model of Organizational Capacity and Maturity

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Abstract. The maturity and capacity of a business are parameters that are directly associated to its quality and experience. In the specialized field of energy performance, these parameters are a determining factor on the reliability of results. In Chile, a lack of codes, standards or norms on energy simulation, it is of vital importance to have a system that is precise in its predictions. This study is centered on determining the level of uncertainty by analyzing different specialized firms in this field, taking into account their level of experience and internal capacities. We analyzed 32 consulting firms in function of their capacities and experience through a matrix of organizational capacity and maturity adapted to the energy efficiency field. To do this, we proposed the following elements of analysis: type of system used for simulation (static-dynamic), qualification of the staff in charge of each study, certification in national or international standards related to the specialty, use of internal work protocols and the existence of a quality assurance system for their processes. It can be expected that the level of reliability increases with firm maturity due to the ponderation that is assigned to each level. At the same time good performance is assured when there exist objective procedures that sustain internal capacities in such a way that the highest levels of predictability are achieved in an optimized atmosphere complemented with quality assurance systems. This tool can serve as a reference for firms in the project design phase, in such way that they can determine the confidence level of a simulation in function of the specialist’s quality and experience.

1. Introduction
The level of maturity and capacity of a business are parameters directly associated to its quality and experience. Regarding a specialized field such as building performance simulation (BPS), these parameters can determine the level of reliability with which results are obtained in different projects. International evidence exists about the use of these tools according to Attia [1], Crawley [2], EDSL-TAS [3], Nyuk [4] and US DOE [5]. Other authors describe the compatibility or combined use of BPS with building information modelling (BIM) Bazjanac [6], Lobos [7], Krygiel [8] y Theßeling [9]. In Chile, there exists a lack of codes, standards or regulations regarding energy simulation that impose referential limits on types of software, specialists, types of buildings, among others. Therefore, it is
vitally important to develop a strategy that is precise in its predictions on energy performance obtained by modelling and simulations with specialized tools.

For BIM, international literature describes its use in construction projects in Mcgraw-Hill [10], Eastman [11], for facility management and building owners in Reddy [12], for government in GSA [13] and for associations in Khemlani [14]. With BIM, it is possible to rely on a centralized nucleus of information, in which all information can be stored to carry out this type of analysis. Therefore, the definitive scope can be determined of an energy simulation in function of a firm; in other words, in function of its capacity and maturity. In this way, it is possible to guarantee real energy performance results taking into account the firm’s state in an organizational maturity matrix (Figure 1). This same analysis can results in an optimum degree of maturity and capacity for the specialty of bioclimatic design or energy efficiency of a building. This method can furthermore identify the capacities and minimum experience required to reduce uncertainty in a particular degree or in general according to each client’s requirement.

In this study, we looked to establish a connection between the final results of energy simulation of a project and its actual performance, taking into account the levels of capacity and maturity of the specialist that carries out the study or consultancy.

Systems of building energy simulation analyze the quality and environmental demand of constructions, but they must have pertinent and reliable procedures, according to García-Alvarado y González [15]. As theoretical studies, they have the capacity to present an approximation to the real performance that a building will have once in use. Among the different variables that can generate uncertainty in the results, one referent study is that of Coakley y Raftery [16] where authors specify internal materials or conditions, modelling errors, numerical errors and errors in supposed scenarios. In each case, it is possible to find different sources of variability for the final results, of which the most important are energy demand and consumption, along with comfortable conditions for users. In general terms, according to Trebliccock and Burdiles [17] processes of energy simulation look to evaluate the theoretical performance of a building by analyzing an entire year of performance, incorporating variables such as climate information (air temperature, relative humidity, solar radiation, wind speed), use conditions (hours, number of inhabitants, types of users), construction characteristics, among others. These types of studies take into consideration the complex environment in which geometrical and construction information will be parameterized, adding an unlimited quantity of assumptions that combine for an estimation of the final energy behavior of a building.

Figure 1. Energy flows in buildings. Taken from Clarke [18].
In Chile, the specialized field of energy efficiency or bioclimatic analysis lacks regulation that establishes standardized procedures in an industry that has over 1000 specialists (considering firms and independent consultants). The sheer number of different professionals with no governing regulation does not add to the universality and standardization of results obtained by each specialist for every study. The energy efficiency field differs from other predictive specialties such as soil mechanics or structural analysis in which, together with engineering (normatively regulated), there exists a series of legal requirements (field studies) to be exhaustively completed by those who execute the project. However, regarding energy efficiency, there is no second party that obligates the construction firm (or the body that executes the project) to corroborate any parameter that has been simulated in the engineering phase, and therefore the reliability of results from energy efficiency simulations are unable to verify on the level of normative requirements.

| Type of project | Examples |
|----------------|----------|
| **BIM** | Private projects of Architecture, Construction and Engineering that have used BIM. |
| **BPS** | Examples of buildings that have been calculated with different BPS software in Chile. |
| **BEAM** | Examples of buildings that have LEED certification in Chile. |
| **CES** | Examples of buildings that have CES certification in Chile. |

Since around the year 2000, there have been diverse methods that allow engineering firms to certify the quality of their work, such as Quality Assurance Systems (2008), the ISO 9001 standard being the most well-known. However, other certification systems exist that allow the certification of work quality together with external technical evaluation for specific specialties such as Building Environmental Assessment Methods (BEAMs). Internationally, the most well-known are LEEDs or PassiveHaus certifications; and nationally the Sustainable Building Certification System (CES) or the recent...
Sustainable Housing Certification System. All these certifications are voluntary, and therefore require an important effort carried out by each building firm in order to highlight their brand and differentiate their service in the construction market (Table 1).

2. Methodology

2.1. Maturity and BIM Capacity

It is possible to determine the performance of a company taking their BIM capacities as a starting point. In other words, the focus and level of integration in the use of this platform in the chain of specializations is associated to the maturity of a firm, in accordance to that proposed by Succar and Williams [19]. From this point, Succar [20] developed a BIM Maturity Index [20] that has also been used in some Latin American countries (Plan BIM 2018). This focus is used in this study to determine the reliability of results obtained by different consulting companies or independent consultants that offer specialized services in Energy Efficiency. Therefore, our proposal is to modify Succar’s BIM Matrix [20], into a subsequent matrix that determines the degree of reliability or certainty reached by a consultancy based on its capacities and internal procedures.

| Table 2. Extract from the BIM Capacity and Maturity Matrix. |
|---|---|---|---|---|---|
| Area | IC | IC | IC | IC |
| Modelling based on use of the discipline in the life cycle of projects | Interface development of practitioners' tools | Implementation of energy simulation strategies | Identification of tools or protocols for energy simulation | Identification of tools or protocols for energy simulation |
| Collaborative matrix based on the level of interconnection of the different levels of the project | Integration of the BIM maturity level | Integration of the BIM maturity level | Integration of the BIM maturity level | Integration of the BIM maturity level |
| Integration based on the life cycle of the project | Integration of the BIM maturity level | Integration of the BIM maturity level | Integration of the BIM maturity level | Integration of the BIM maturity level |

2.2. Matrix of maturity and capacity for BIM-BPS

The Maturity Index by Succar [20] is used as a reference to determine a firm’s state of maturity and BIM capacity. This index allows comparison between performance, quality and experience of different companies that offer the same service. Thus, it is proposed to identify each firm’s capacities in function of the information modelled in each case. For BIM, Table 3 presents the 3 options identified by Succar [19], and a score is assigned from 1 to 7, according to each firm’s degree of maturity.

Given the problem defined in this study, with regards to the inexistence of regulations associated to this specialization, nine elements of Capacity are taken as objective starting points used for later comparison. Capacity is defined according to its initially proposed definition, and directing it to the internal capacities of a firm that influence (theoretically) the level of uncertainty in the results of energy simulation analyses. These nine levels are:

2.2.1. No system.

Refers to the inexistence of procedures or protocols for energy simulation, treating every client in a personalized manner, and without direction that allows comparable results between different firms.
2.2.2. **Static simulation.**
Corresponds to a simulation process through static tools, restricting the incorporation of determinant variables in energy behavior calculations, considering initial suppositions to replace these variables. Usually Excel spreadsheets are used for calculations, developed by each organization or consultant.

2.2.3. **Dynamic Simulation.**
Simulation is done with specialized software such as TAS, DesignBuilder, EnergyPlus, BLAST, DOE-2, Trnsys, IES, eQUEST, among others. These programs allow calculations for every hour of the year, hourly variations in occupancy, lighting, equipment, thermostat and acclimatization system configuration, thermal inertia effect, and many other variables.

2.2.4. **Qualified Professionals:**
Years of experience and specializations of professionals that work on the simulations.

2.2.5. **Internal Protocols.**
Protocols that guarantee that the internal processes of the organization are registered and documented, similar to what is established by a quality assurance system; or a standard developed by the company, that allows follow-up of each job carried out, identifying activities and responsible parties in each case.

2.2.6. **Declaration of adhesion to international standards.**
Understood as an effort by the company to obtain comparable and technically verifiable results. Such protocols include those defined in ASHRAE 209-2018 “Design assisted by energy simulation for buildings except low-rise residential buildings.” These protocols are explicitly detailed for the specialization of energy simulation, and serve as a guide for specialists who carry out this type of consultancy. However, work carried out under this type of regulation is not certified by any national agency.

2.2.7. **Quality assurance system.**
Generic procedures that can be applied to any company and that are not directly related to energy efficiency or simulation. The most well-known standard is the ISO 9001:2015. Requirements for a Quality Management System. The level of incidence that this certification has in internal processes obligates the specialist to maintain a series of activities that guarantee the final quality of the job. As a point of differentiation, in order for a firm to certify itself with this standard, it is necessary to carry out external audits by an agency accredited by the Instituto Nacional de Normalización (National Institute of Standardization).

2.2.8. **International Certification System.**
Commonly known for representing a differentiating factor for large construction projects in the realm of energy efficiency or sustainable construction. Among the most used on a worldwide level are PassiveHaus, a German standard for the construction and certification of residences that have comfortable interior climates; or Leadership in Energy and Environmental Design (LEED) certification for sustainable buildings, developed by the US Green Building Council (GBC). The latter has among its requirements for energy simulation, the use of requirements such as ASHRAE and the work is validated and certified by an international entity (GBC).

2.2.9. **National Certification System.**
The structure of Certification Systems tends to be very similar to foreign systems, however, they have the advantage of incorporating parameters and variables that are only applicable to the national reality. For this reason, the degree of confidence of the results increases, due to specific requirements and particular territorial conditions with which a firm must comply. In Chile, two systems exist, the Sustainable Building Certification (CES) a national system that evaluates, qualifies and certifies the
environmental behavior of public use buildings; and the Residential Energy Qualification (CEV), an instrument designed in 2012 that looks to improve the quality of life for families through providing objective and standardized information.

In this study, these nine levels of capacity were used to homogenize what was developed by Succar [20], defining on each level, in function of the degree of maturity of each firm, a score on a 1-7 scale. To elaborate the reliability scale within the matrix, an evaluation was done of 32 projects, each associated to a consulting firm, distributed by municipality (Figure 2).

**Figure 2.** Buildings with Energy Efficiency projects chosen for audit.

For each project and organization analyzed, an audit is carried out that collects information about the organizations in charge of these simulations, revising in each case the relevant parameters mentioned previously, which complement the following information (Table 3). In this case, for each level of capacity, a score is assigned that gives each a value. It is important to underline that the confidence level is established a priori, given that to arrive at a real value of energy performance through simulation, it is necessary to analyze each finished project in operation during a continual period of one year. Therefore, this study pretends to establish equality in conditions how reliable the simulation results are after completing the building project.

### Table 3. Evaluated requirements in the capacities audit.

| Capacity Evaluated          | Audited Requirement                                      | Score |
|-----------------------------|----------------------------------------------------------|-------|
| No System                   | -                                                        | 0,1   |
| Static Simulation           | Excel spreadsheets are used for calculations.             | 0,1   |
| Dynamic Simulation          | Use of specialized software                              | 0,5   |
|                             | Defined comfort ranges                                   |       |
|                             | Air renewal                                              |       |
|                             | Internal charges                                         |       |
|                             | Thermal inertia                                          |       |
| Qualified Professional      | Years of experience                                      | 0,5   |
|                             | Profession                                              |       |
|                             | Specializations                                          |       |
| Internal Protocols          | Quality procedures                                       | 0,6   |
|                             | Evidence                                                |       |
|                             | Control                                                 |       |
| International Standard      | Use of specialized software                              | 0,7   |
| Capacity Evaluated | Audited Requirement                                                                 | Score |
|--------------------|-------------------------------------------------------------------------------------|-------|
|                    | Defined ranges of comfort Air Renewal Internal charges Thermal inertia                |       |
| International      | Certified by an Organism Use of specialized software Defined ranges of comfort Air renewal Internal charges Thermal inertia | 0,8   |
| National Certification | Certified by an Organism Use of specialized software Defined ranges of comfort Air renewal Internal charges Thermal inertia | 1     |
| ISO 9001           | Certified by an external Organism Quality Procedures Evidence Control                 | 1,2   |

3. Results

Results from the audits are presented in Table 4. Here, the sum or total points obtained are shown for each organization. For this case, negative scores were given for organizations that indicated “No System” and “Static Simulation.”
Table 4. Audit results for the capacities of each organization.

| Firm   | Project          | No System | Static Simulation | Dynamic Simulation | Qualified Professional | Internal Protocols | International Standard | International Certification | National Certification | ISO 9001 | Sum |
|--------|------------------|-----------|-------------------|--------------------|------------------------|--------------------|-----------------------|--------------------------|------------------------|-----------|-----|
| Firm 1 | Rapa Nui 1       | 1         | 1                 | 1                  | 0                      | 1                  | 0                     | 1                        | 0                      | 2         | 4.4 |
| Firm 2 | Rapa Nui 2       | 0         | 0                 | 1                  | 1                      | 0                  | 1                     | 1                        | 1                      | 0         | 3.5 |
| Firm 3 | Rapa Nui 3       | 0         | 0                 | 1                  | 0                      | 1                  | 1                     | 1                        | 1                      | 0         | 2.9 |
| Firm 4 | Juan Fernández 1 | 0         | 0                 | 1                  | 1                      | 1                  | 1                     | 0                        | 1                      | 1         | 3.3 |
| Firm 5 | Juan Fernández 2 | 0         | 0                 | 1                  | 1                      | 0                  | 1                     | 1                        | 1                      | 0         | 2.8 |
| Firm 6 | Juan Fernández 3 | 0         | 0                 | 1                  | 1                      | 1                  | 1                     | 1                        | 1                      | 0         | 4.1 |
| Firm 7 | Lo Barnechea     | 0         | 0                 | 1                  | 0                      | 1                  | 0                     | 0                        | 1                      | 0         | 2.1 |
| Firm 8 | Collina 1        | 1         | 1                 | 0                  | 1                      | 1                  | 1                     | 0                        | 1                      | 0         | 3   |
| Firm 9 | Collina 2        | 0         | 0                 | 1                  | 1                      | 0                  | 0                     | 0                        | 0                      | 1         | 1   |
| Firm 10| Lampa 1          | 0         | 1                 | 0                  | 0                      | 0                  | 0                     | 1                        | 0                      | 1         | 2.6 |
| Firm 11| Lampa 2          | 0         | 0                 | 1                  | 0                      | 1                  | 0                     | 1                        | 0                      | 1         | 3.1 |
| Firm 12| Huachuraba       | 0         | 0                 | 3                  | 0                      | 0                  | 1                     | 1                        | 1                      | 0         | 3   |
| Firm 13| Estación Central 1| 0         | 0                 | 1                  | 0                      | 1                  | 1                     | 1                        | 1                      | 0         | 3.6 |
| Firm 14| Estación Central 2| 0         | 0                 | 1                  | 0                      | 1                  | 1                     | 1                        | 1                      | 0         | 4.1 |
| Firm 15| Marqués          | 0         | 0                 | 1                  | 0                      | 1                  | 1                     | 1                        | 0                      | 1         | 3.4 |
| Firm 16| Puente Alto 1    | 0         | 0                 | 1                  | 0                      | 1                  | 0                     | 1                        | 1                      | 1         | 4.1 |
| Firm 17| Puente Alto 2    | 0         | 0                 | 1                  | 0                      | 0                  | 0                     | 1                        | 1                      | 1         | 2.7 |
| Firm 18| Puente Alto 3    | 0         | 0                 | 1                  | 1                      | 0                  | 1                     | 0                        | 1                      | 1         | 3.9 |
| Firm 19| Puente Alto 4    | 0         | 0                 | 1                  | 0                      | 1                  | 0                     | 1                        | 0                      | 1         | 2.2 |
| Firm 20| Puente Alto 5    | 0         | 0                 | 1                  | 0                      | 1                  | 1                     | 1                        | 1                      | 0         | 3.6 |
| Firm 21| Concepción 1     | 0         | 0                 | 1                  | 0                      | 0                  | 0                     | 1                        | 1                      | 0         | 2.3 |
| Firm 22| Concepción 2     | 0         | 0                 | 1                  | 0                      | 0                  | 0                     | 1                        | 1                      | 0         | 2.7 |
| Firm 23| Concepción 3     | 0         | 0                 | 1                  | 0                      | 1                  | 0                     | 0                        | 1                      | 1         | 3.5 |
| Firm 24| Temuco 1         | 0         | 0                 | 1                  | 0                      | 1                  | 0                     | 0                        | 1                      | 1         | 3.3 |
| Firm 25| Temuco 2         | 0         | 0                 | 1                  | 1                      | 1                  | 1                     | 0                        | 1                      | 0         | 3.3 |
| Firm 26| Temuco 3         | 0         | 0                 | 1                  | 1                      | 0                  | 0                     | 1                        | 1                      | 0         | 2.8 |
| Firm 27| Curarrehue       | 0         | 0                 | 1                  | 0                      | 0                  | 0                     | 1                        | 1                      | 0         | 2.1 |
| Firm 28| Osorno           | 0         | 0                 | 1                  | 0                      | 0                  | 0                     | 1                        | 1                      | 1         | 4.2 |
| Firm 29| Castro           | 0         | 0                 | 1                  | 0                      | 1                  | 1                     | 1                        | 1                      | 0         | 4.2 |
| Firm 30| Aysén            | 0         | 0                 | 1                  | 1                      | 0                  | 0                     | 0                        | 1                      | 0         | 2.2 |
| Firm 31| Coyhaique        | 0         | 0                 | 1                  | 0                      | 1                  | 0                     | 0                        | 1                      | 1         | 4   |
| Firm 32| Punta Arenas     | 0         | 0                 | 1                  | 1                      | 1                  | 0                     | 1                        | 1                      | 1         | 5.5 |

Generally, results indicated that organizations that execute the specialization BPS through dynamic tools, complemented by national certification differentiate themselves from their competition, and validate their results through organisms responsible for these quality assurance systems. At the same time, through the audits, it was possible to determine the state of maturity for each organization, according to the capacity’s matrix indicated in the methodology section (Table 5).
Table 5. Audit results for the maturity level of each organization.

| Firm | Initial | Defined | Managed | Integrated | Optimized |
|------|---------|---------|---------|------------|-----------|
| Firm 1 | 1       |         |         |            |           |
| Firm 2 |         | 1       |         |            |           |
| Firm 3 |         |         | 1       |            |           |
| Firm 4 |         |         |         | 1          |           |
| Firm 5 |         |         |         |            | 1         |
| Firm 6 |         |         |         |            |           |
| Firm 7 |         |         |         |            | 1         |
| Firm 8 |         |         |         | 1          |           |
| Firm 9 |         |         |         |            | 1         |
| Firm 10 |         |         |         |            |           |
| Firm 11 |         |         |         |            |           |
| Firm 12 |         |         |         |            |           |
| Firm 13 |         |         |         |            |           |
| Firm 14 |         |         |         |            |           |
| Firm 15 |         |         |         |            |           |
| Firm 16 |         |         |         |            |           |
| Firm 17 |         |         |         |            | 1         |
| Firm 18 |         |         |         |            | 1         |
| Firm 19 |         |         |         | 1          |           |
| Firm 20 |         |         |         |            |           |
| Firm 21 |         |         |         |            | 1         |
| Firm 22 |         |         |         |            | 1         |
| Firm 23 |         |         |         |            |           |
| Firm 24 |         |         |         |            | 1         |
| Firm 25 |         |         |         |            | 1         |
| Firm 26 |         |         |         |            |           |
| Firm 27 |         |         |         |            |           |
| Firm 28 |         |         |         |            |           |
| Firm 29 |         |         |         |            |           |
| Firm 30 |         |         |         |            | 1         |
| Firm 31 |         |         |         |            | 1         |
| Firm 32 |         |         |         |            | 1         |

Results concentrate maturity levels in three central phases, finding a lower quantity of firms in the Initial and Optimized stages. In the definition of each degree of compliance, the level of certainty is associated to different capacities that constitute an energy simulation study. Information declared by each firm and the characteristics of each work system associated to these capacities were used as a basis for this classification (Table 6).

Table 6. Indicator of Certainty associated to capacities in the specialization of energy simulation.

| Confidence level                          | Initial | Defined | Managed | Integrated | Optimized |
|------------------------------------------|---------|---------|---------|------------|-----------|
| No system                                |         |         |         |            |           |
| Static simulation                        | 1%      | 2%      | 3%      | 6%         | 6%        |
| Dynamic simulation                       | 3%      | 9%      | 16%     | 29%        | 32%       |
| Qualified professional                   | 3%      | 9%      | 16%     | 29%        | 32%       |
| Internal protocols                       | 4%      | 11%     | 19%     | 35%        | 38%       |
| Declaration of adhesion to international regulations | 8%      | 13%     | 22%     | 41%        | 45%       |
| International certification system       | 9%      | 14%     | 25%     | 46%        | 51%       |
| National certification system            | 10%     | 18%     | 32%     | 58%        | 64%       |
| Quality assurance system                 | 11%     | 22%     | 38%     | 69%        | 76%       |
In this way, the optimum level is determined that guarantees a degree of reliability in the highest quantile of the scale, which can be obtained in 12 different scenarios out of 40 possible (Figure 3).

This determines that the minimum capacities of a firm to be considered within the highest quantile of reliability, whose state of maturity is Managed, must incorporate certification on a national level. Or, if the firm is on an Integrated level, it is sufficient to incorporate a quality assurance system into its internal procedures. As such, the firm must certify its processes and activities by an external entity.

**Figure 3.** Values represented as percentages of BPS Capacity and Maturity.

4. Discussion y conclusions

It can be expected that the level of reliability increases as a business’ maturity increases, due to the weighting that is assigned at each level. At the same time a good performance level is guaranteed where objective procedures exist that sustain internal capacities. Maximum levels of predictability are reached in an optimized work environment complemented with a quality assurance system; or in an environment that incorporates the Sustainable Certification protocols at a national level (64%).

For the analyzed cases, a higher concentration was found of organizations in central phases of maturity (Defined, Managed and Integrated), together with the use of dynamic simulations and adherent to the National Certification Standards.

We hope that this methodology can be a reference for building tenders in the preliminary drafting stage, in such a way that they can analyze results of a simulation in function of the quality and experience of the specialist.

On the other hand, this study proposes a research topic that tackles the contrast between the confidence levels of energy simulations in regards to the real energy consumption that each building presents. In these situations it is necessary to perform energy audits on buildings that are already constructed, in which other determinant factors intervene such as the quality in execution and energy management of each project.
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