



**Marco André
Santos Rodrigues**

**Estágio na Empresa SPRAL, Sociedade de
Pré-Esforçados de Aveiro, Lda.**

**Internship at SPRAL, Sociedade de
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Dissertação apresentada à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do grau de Mestre em Engenharia Civil, realizada sob a orientação científica do Doutor Miguel Nuno Lobato de Sousa Monteiro de Moraes, Professor Auxiliar do Departamento de Engenharia Civil da Universidade de Aveiro.

júri

presidente

Professor Doutor Joaquim Miguel Gonçalves Macedo

Professor auxiliar da Universidade de Aveiro

Professor Doutor Miguel Nuno Lobato de Sousa Monteiro de Morais

Professor auxiliar da Universidade de Aveiro (Orientador)

Professor Doutor Domingos António Garcia Ribas

Professor Adjunto do Instituto Politécnico de Viana do Castelo

agradecimentos

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palavras-chave

estágio, spral, betão, pré-fabricação, pré-esforço, certificação, np en 206-1:2007, laboratório, vb.net, c#

resumo

Estágio com forte destaque da componente prática na empresa Spral – Sociedade de Pré-Esforçados de Aveiro, Lda. com o intuito de se proceder à certificação da produção de betão fresco de acordo com a norma NP EN 206-1:2007. É apresentada uma descrição dos trabalhos iniciais, do processo de certificação e do trabalho realizado ao longo do período de estágio.

Houve lugar ao desenvolvimento de trabalho de laboratório com diversas finalidades, colocando em prática metodologias normalizadas com ligeiras adaptações à realidade da empresa e dos trabalhos em questão.

Para responder a necessidades específicas da empresa, foram desenvolvidas diferentes soluções de software em *VB.NET* e *C#* para aumentar a produtividade em atividades relacionadas com a Engenharia Civil. Apresenta-se a linha de pensamento, detalhes de cálculo e exemplos práticos do seu funcionamento.

keywords

internship, spral, concrete, precast, prestressed, certification, np en 206-1:2007, laboratory, vb.net, c#

abstract

Internship at SPRAL – Sociedade de Pré-Esforçados de Aveiro, Lda., with strong focus on the practical component with intent to complete the certification of fresh concrete production according to NP EN 206-1:2007. This report includes a description of the initial activities, the certification process and the work developed during the internship period.

Different activities required laboratory work, which resulted in the application of methodologies from various norms with the necessary adaptations taking in consideration the company and the objective.

As an answer to specific needs of the company, software tools were developed using *VB.NET* and *C#*, to improve the productivity in activities related with Civil Engineering. This report includes the motivation, calculation details and practical examples of its usage.

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List of Acronyms

APEB – Associação Portuguesa de Empresas de Betão Pronto

API – Application Programming Interface

CAD – Computer-Aided Design

CSV – Comma-Separated Values

EC0 – Eurocode 0

EC1 – Eurocode 1

ID – Identity Document

IPAC – Instituto Português de Acreditação

REBAP – Regulamento de Estruturas de Betão Armado e Pré-esforçado

SLS – Serviceability Limit State

ULS – Ultimate Limit State

VB.NET – Visual Basic .NET

List of Symbols

Latin upper case letters

A_s – Cross sectional area of reinforcement

$A_{s_{long}}$ – Cross sectional area of longitudinal reinforcement

$A_{s_{transv}}$ – Cross sectional area of transversal reinforcement

C# – C Sharp

D – Solid end distance

EI – Bending stiffness

G – Dead/permanent load

L – Span

M_{fctk} – Design cracking moment

M_{freq} – Bending moment for frequent action values

M_{rd} – Resistant value for bending moment

M_{sd} – Design value of the applied bending moment

P_{sd} – Design value for load

Q – Variable load

V_{ed} – Design value of the applied shear force

V_{rd} – Resistance value for shear force

Latin lower case letters

b – Overall width of the cross-section

d_{lt} – Long term deflection

f_{cd} – Design value of concrete compressive strength

f_{yd} – Design yield strength of reinforcement

n – Factor related to the position of the slab

Greek letters

ϕ – reinforcement bar diameter

μ – reduced moment

φ – creep factor

Ψ – factors defining representative values of variable actions

ω – mechanical reinforcement ratio

Chapter 1

INTRODUCTION

1. INTRODUCTION

This report is the result of a 9 month internship that started on October 2014 and ended on July 2015. The daily schedule (Table 1.1) was set according to the University timetable.

Table 1.1. Internship Timetable

	Monday	Tuesday	Wednesday	Thursday	Friday
8:30am-12:00pm		✓	✓	✓	✓
2:00pm-6:00pm	✓		✓		✓

1.1. ABOUT SPRAL – SOCIEDADE DE PRÉ-ESFORÇADOS DE AVEIRO, LDA



Figure 1.1. Logo SPRAL – Sociedade de Pré-Esforçados de Aveiro, Lda

SPRAL – Sociedade de Pré-Esforçados de Aveiro, Lda (Figure 1.1), hereinafter referred to as SPRAL, is a company specialized in precast and prestressed concrete elements. This company started its activity in 1966 and was acquired by *Mário Almeida* group in 2001, being a key part of the group since then.

Along the years SPRAL has expanded its product portfolio from the initial precast and prestressed concrete parts, blocks and lightweight beams to include heavy-duty precast concrete elements (Figure 1.2).



Figure 1.2. Heavy duty precast element

SPRAL performs its activities in an 80.000 m² industrial complex located in Moitinhos, Ílhavo (Figure 1.3), providing job to more than 75 people.



Figure 1.3. Aerial view of SPRAL

SPRAL works according to NP EN ISO 9001:2000 quality manager systems. Several of its products have CE Marking following requirements of Council Directive 89/106/CEE relating to construction products.

1.1.1. Lightweight precast products

In terms of masonry, the products available are structural, facade, lightweight, thermal, split and technical blocks. All of these are precast concrete with different components to meet different requirements that are suitable or necessary to certain applications.

Precast solutions for motorways and residential areas include concrete pavers, grass blocks, kerbs, safety barriers for motorways and highway tolls, protection for gas pipelines and street gutters.

For slabs and roof support systems, SPRAL offers solutions for roof support beams, all the elements needed for rib and block slabs (Figure 1.4), lightweight clay blocks for flat slabs which are ideal to reduce the overall weight of structural elements but also allow for a much faster and safer construction process.



Figure 1.4. Prestressed beams

Products for sanitation and infrastructures include concrete pipes, eccentric cones,

drain manholes, concrete junction boxes, drainage channels, foundation for utility poles and ecotainers.

1.1.2. Heavy-duty precast products

SPRAL's solution for slabs in category of heavy-duty precast come in a variety of hollow-core slab panels (Figure 1.5).



Figure 1.5. Hollow-core slab panels

Structural elements for industrial halls, facade panels and stadium seating are also part of the product list.

For other more specific constructions like bridges, SPRAL has T beams, pre-slabs and other non-structural elements, for seashore constructions there are different platforms for wharfage and submarine emissary. Railroad solutions include precast boarding platforms, easy and fast to install.

Products for sanitation and infrastructures include culverts and wingwalls.

Other than that, the precast catalogue also includes retention walls and concrete wall fences.

1.1.3. Fresh concrete production

There are different types of fresh concrete available on request besides the regular concrete (Figure 1.6) with resistance classes from C16/20 to C35/45, namely special concrete with superior resistance, lightweight concrete and architectural concrete.



Figure 1.6. Fresh concrete

Recently improved the concrete production business unit, with support and technical staff, vehicles and machines as well as a dedicated concrete production plant with 30m³/h of production capacity. The owner of *Mário Almeida* group is very experienced in this field, as previous owner of one of the regional leaders in fresh concrete production during the 90s, *Almeida e Carvalhais, Lda*.

1.1.4. Other companies of the group

Alongside SPRAL, *Mário Almeida* group includes four more companies each one dedicated to a specific market but with a logical connection between all.

The first company of the group is dedicated to extraction, washing and classification of aggregates. Today goes under the name of *MA Inertes* and it is still a core unit of

the group. SPRAL and *Biltec* use these products but so do other companies that operate in the construction business.

Biltec is the company specialized in construction, from project to execution with capacity to provide solutions in a wide spectrum of situations from industrial to housing and even motorways.

MA Transportes is the company dedicated to the transportation of the products from the other companies in the group to their customers.

MA Investimentos Imobiliários explores opportunities related with buying and selling of terrains, office buildings and houses.

1.2. STRUCTURE OF THE REPORT

The main focus of the internship was the certification of fresh concrete production. Along the way, other activities were added to the internship including laboratorial work and software development.

After this short introduction, with a description of the host company, SPRAL – *Sociedade de Pré-Esforçados de Aveiro, Lda.*, and its products, comes chapter two that is related to the certification, with information regarding the process itself and more details of the work that was developed towards the certification with description of the methodologies used.

Next chapter refers to other activities developed during the internship period. The internship was heavily focused on laboratorial work for different intents and the objectives and methodologies used are explained. This chapter also includes the development of software tools focused on productivity of tasks related to civil engineering.

The last chapter presents the final thoughts on this internship, the conclusions and adds ideas and suggestions on what could be done in the future.

Chapter 2

CERTIFICATION OF FRESH CONCRETE PRODUCTION

2. CERTIFICATION OF FRESH CONCRETE PRODUCTION

The certification of fresh concrete production is according to NP EN 206-1:2007 and DL 301/2007 from August 23rd. The details of the process may vary by certification body.

All the activities regarding this topic started in October, under the technical guidance of Eng. José Rebelo. The entire process was expected to take around six months to complete, according to previous experience with certification processes by the host company and after the initial evaluation of the production. In the end, it lasted the entire nine month of internship. Some generic aspects of the production control system were already in place due to the compliance with ISO 9001:2000.

With the construction industry pretty much stagnated and the need of companies to win every project, combined with the fact that consumer standards only get higher, the certification of fresh concrete production can easily be the deciding factor as it enhances the confidence on the final product. For the producer it is also beneficial to have implemented a more rigorous control system in order to save money on the concrete composition for different families and more important, to avoid having any fresh concrete load rejected at the construction site because it does not meet the requirements in terms of consistency.

This certification is required for class 3 inspection works. For class 2 inspection works, it is required to proceed to sampling and identity testing. For works that are classified as class 1 inspection, it is only needed to proceed with sampling and identity tests if specified on the project design. As a guide to the inspection class one can use the execution classes established on NP ENV 13670-1 (Table 2.1).

Table 2.1. Guide to select the inspection class (NP ENV 13670-1)

Parameter	Class 1	Class 2	Class 3
Type of construction	- Buildings ≤ 2 storey	- Buildings > 2 storey - Bridges	- Buildings > 12 storey - Special bridges - Dams - Nuclear plants - Reservoirs
Structural elements	- Concrete beams and slabs with span ≤ 10 meters - Columns and walls - Structures with simple foundations	- Reinforced concrete beams and slabs with span > 10 meters - Slim columns and walls - Pile caps - Arches with span ≤ 10 meters	- Reinforce concrete arches and vaults - Highly compressed elements - Special foundations - Arches with span > 10 meters
Type of construction/ technologies	- Structures with precast elements	- Structures with precast elements	- Structures with precast elements - Special limits
Compressive strength class	- C25/30	- Any compressive strength class	- Any compressive strength class
Exposure class	- X0, XC1, XC2	- Any exposure class	- Any exposure class
Reinforcement	- For reinforced concrete	- For reinforced concrete and prestressed	- For reinforced concrete and prestressed

2.1. CERTIFICATION PROCESS

The certification is requested by the concrete producer and conducted by a certification body accredited by the national accreditation body, IPAC (*Instituto Português de Acreditação*), and goes as follow (IPAC, 2008):

2.1.1. Collecting samples and laboratory testing

At the beginning of each inspection, the certification body is responsible for collecting samples and perform the slump test and compression strength test under the standards NP EN 206-1:2007, NP EN 12350-1:2002, NP EN 12350-2:2002 Part 2, NP EN 12390-2:2003 Part 2, NP EN 12390-3:2003 Part 3. Each sample should

have one slump test and three cubes to test at 28 days of age. The producer should take its own samples from the same concrete batch.

2.1.1.1. Initial inspection

This first inspection includes taking samples from at least three batches of concrete, preferably from different classes of resistance.

The objective of this inspection is to determine if the staff and equipment at the production plant are suitable for fresh concrete production its control. The documentation related to the production and testing is also inspected.

2.1.1.2. Regular inspections

The certification body has to perform inspections at least twice a year without advance notice. At every inspection a sample of concrete should be collected.

2.1.2. Evaluation of testing results

2.1.2.1. Consistency

According to NP EN 206-1:2007 there are five slump classes (Table 2.2). At *SPRAL*'s fresh concrete production plant the most common required classes are S2, S3 and S4, depending on the objective and how the concrete will be cast at the construction site. Ultimately, *SPRAL* only advises on which class should be used in each situation as the final decision is always the customer's responsibility, inside reasonable limits, in order to prevent damaging *SPRAL*'s pump, for example.

Table 2.2. Slump Classes (NP EN 206-1:2007)

Class	Slump (mm)
S1	10 to 40
S2	50 to 90
S3	100 to 150
S4	160 to 210
S5	≥ 220

Slump test is only recommended for consistency between 10 millimetres and 210 millimetres. Outside this range, the test lacks sensitivity.

It was noted that substantial weather changes would affect the concrete consistency, which would still comply with NP EN-206-1:2007 requirements using the maximum deviations (Table 2.3).

Table 2.3. Tolerances for target values of consistence (NP EN 206-1:2007)

Slump			
Target value in mm	≤ 40	50 to 90	≥ 100
Tolerance in mm	± 10	± 20	± 30

Slump test is performed at the production plant or on site, sometimes both (Figure 2.1). This is a very important test and customers are really strict with results. The process respected the standard NP EN 12350-2 as much as possible. The equipment needed includes a baseplate, a standard slump cone, rounded tip tamping rod, hand shovel and a ruler.

Although it is not really a problem in Aveiro, the temperature was measured in different situations along the tests. This provides additional information as the temperature affects the rate at which concrete gains strength and the ultimate

strength it acquires. When the mixer truck arrives to the sampling area, the air temperature is measured with a classic mercury thermometer and registered.

A portion of fresh concrete is transferred from the concrete mixer truck to a wheelbarrow. When possible sample is remixed with a shovel until it has a uniform appearance. Right after collecting the sample from the concrete mixer truck, the temperature of fresh concrete is measured. A metal immersion type thermometer is used. It is inserted on the sample for approximately 2 minutes and the temperature is read and registered. The sample should be as representative as possible and ideally never from the first 0,3 m³ but in reality it was usually taken from the beginning of the discharge. If the slump result is out of the limits of the class required, the concrete will not be cast. When performed at the production plant this test allows to adjust the composition for the next truck if needed and gives opportunity to small adjustments that can be made during transport, such as change the mixer speed. At the construction site this test is a validation that will determine if the concrete is cast or returned.



Figure 2.1. Slump test at construction site

The baseplate and the slump cone are damped to avoid water absorption and also to avoid concrete to stick to the cone walls.

The cone is filled using a rectangular hand shovel in three layers with approximately volume. The last one should overtake the cone in a way that after compacting the concrete never goes below the cone entrance. At the end of each layer, the concrete is compacted with 25 strokes of the tamping rod spread evenly across the cross section of each layer. The tamping rod should not hit the baseplate and should only penetrate the last layer added. The excess of concrete should be removed from the top and from the baseplate to avoid creating resistance to the concrete slumping.

After this the cone is removed in a continuous movement. The cone is turned upside down, the tamping rod is placed on the top of the cone and the distance in height from the cone to the highest point of concrete is measured using a ruler. The result is approximated to the nearest 10 millimetres value.

This test is performed in 150 seconds, from the moment when the filling start to the measurement of the slump distance.

2.1.2.2. Compression strength

The difference between the results from the producer and the certification body should not be higher than 10%. In the case of initial inspection or other occasion where there is more than one sample, this 10% limit is relative to the average result of all samples.

Cube samples can be made at the production plant or at the construction site. This test can be requested by the customer or used for certification and internal quality control.

On the fresh concrete business division, these tests followed a sampling plan to meet the requirements for certification of fresh concrete production under NP EN 206-1:2007 (Table 2.4).

Table 2.4. Minimum rate of sampling (EN NP 206-1:2007 Amendment 1)

Inspection class	concrete with production control certification	concrete without production control certification
1 and 2	1/100 m ³ , minimum of 1/production day	1/50 m ³ , minimum of 1/production day
3	1/50 m ³ , minimum of 1/production day	Not applicable

Additional samples could be required by the customer. Usually were taken four cubes per sample, more than 400 cubes during the internship period (including samples from fresh concrete, precast and prestressed production plants). The compression test is performed on the 7th and 28th day (Figure 2.2).

REGISTO DE ENSAIOS DE LABORATÓRIO										ANO:				
RECOLHA DE AMOSTRAS DO BETÃO PRONTO/RESULTADOS										Série B - Betão Pronto				
Am.	Data Produção	Hora Prod.	Classe Abaix. Abaix.	Classe Resistência	Cliente	Obra/Peça	Local colheita	Nº Composição	l	Data Ensaio	Idade dos provetes	Peso (g)	Força (KN)	Tensão Rotura (Mpa)
62AB	16-10-2014	9:40	140	C20/25 S3 D22 CZ			Obra	502253220403	189C	23-10-2014	7	8146	642,15	28,54
62BB	16-10-2014	9:40	140	C20/25 S3 D22 CZ			Obra	502253220403	189C	13-11-2014	28	8014	616,50	27,40
62CB	16-10-2014	9:40	140	C20/25 S3 D22 CZ			Obra	502253220403	189C	13-11-2014	28	8196	666,68	29,63
62DB	16-10-2014	9:40	140	C20/25 S3 D22 CZ			Obra	502253220403	189C	13-11-2014	28	8152	630,00	28,00
63AB	21-10-2014	9:36	140	C25/30 S3 D22 XC2			Obra	502253220403	189C	28-10-2014	7	8367	857,03	38,09
63BB	21-10-2014	9:36	140	C25/30 S3 D22 XC2			Obra	502253220403	189C	18-11-2014	28	8018	985,05	43,78
63CB	21-10-2014	9:36	140	C25/30 S3 D22 XC2			Obra	502253220403	189C	18-11-2014	28	8224	986,85	43,86
64AB	22-10-2014	9:36	150	C25/30 S3 D22 XC2			Obra	502253220403	259C	29-10-2014	7	8026	708,30	31,48
64BB	22-10-2014	9:36	150	C25/30 S3 D22 XC2			Obra	502253220403	259C	29-10-2014	7	8227	727,43	32,33
64CB	22-10-2014	9:36	150	C25/30 S3 D22 XC2			Obra	502253220403	259C	19-11-2014	28	8046	897,08	39,87
64DB	22-10-2014	9:36	150	C25/30 S3 D22 XC2			Obra	502253220403	259C	19-11-2014	28	8136	797,40	35,44
65AB	22-10-2014	15:39	150	C35/45 S3 D22 X53			Central	502453220201	259C	29-10-2014	7	8111	1009,13	44,85
65BB	22-10-2014	15:39	150	C35/45 S3 D22 X53			Central	502453220201	259C	29-10-2014	7	8039	952,88	42,35
65CB	22-10-2014	15:39	150	C35/45 S3 D22 X53			Central	502453220201	259C	19-11-2014	28	8090	1478,03	65,69
65DB	22-10-2014	15:39	150	C35/45 S3 D22 X53			Central	502453220201	259C	19-11-2014	28	8080	1431,00	63,60
66AB	24-10-2014	10:37	110	C20/25 S3 D22 CZ			Obra	502253220403	249C	31-10-2014	7	8133	529,65	23,54
66BB	24-10-2014	10:37	110	C20/25 S3 D22 CZ			Obra	502253220403	249C	31-10-2014	7	8074	523,35	23,26
66CB	24-10-2014	10:37	110	C20/25 S3 D22 CZ			Obra	502253220403	249C	21-11-2014	28	8199	695,03	30,89
67AB	24-10-2014	16:17	120	C20/25 S3 D22 CZ			Obra	502253220403	259C	31-10-2014	7	8069	429,30	19,08
67BB	24-10-2014	16:17	120	C20/25 S3 D22 CZ			Obra	502253220403	259C	31-10-2014	7	8159	429,08	19,07
67CB	24-10-2014	16:17	120	C20/25 S3 D22 CZ			Obra	502253220403	259C	21-11-2014	28	7928	611,78	27,19
67DB	24-10-2014	16:17	120	C20/25 S3 D22 CZ			Obra	502253220403	259C	21-11-2014	28	8023	627,08	27,87
68AB	29-10-2014	14:51	130	C16/20 S3 D22 X0			Central	502203221002	209C	26-11-2014	28	8164	484,65	21,54
68BB	29-10-2014	14:51	130	C16/20 S3 D22 X0			Central	502203221002	209C	26-11-2014	28	8114	522,23	23,21
68CB	29-10-2014	14:51	130	C16/20 S3 D22 X0			Central	502203221002	209C	26-11-2014	28	8125	514,35	22,86
68DB	29-10-2014	14:51	130	C16/20 S3 D22 X0			Central	502203221002	209C	26-11-2014	28	8072	545,18	24,23
69AB	29-10-2014	16:13	150	C35/45 S3 D22 X53			Central	502453220201	209C	26-11-2014	28	8099	1573,43	69,93
69BB	29-10-2014	16:13	150	C35/45 S3 D22 X53			Central	502453220201	209C	26-11-2014	28	7995	1470,38	65,35
69CB	29-10-2014	16:13	150	C35/45 S3 D22 X53			Central	502453220201	209C	26-11-2014	28	8150	1519,20	67,52
69DB	29-10-2014	16:13	150	C35/45 S3 D22 X53			Central	502453220201	209C	26-11-2014	28	8173	1526,18	67,83
70AB	30-10-2014	10:57	100	C20/25 S3 D22 CZ			Obra	502253220403	189C	27-11-2014	28	7967	619,20	27,52
70BB	30-10-2014	10:57	100	C20/25 S3 D22 CZ			Obra	502253220403	189C	27-11-2014	28	8044	648,90	28,84
70CB	30-10-2014	10:57	100	C20/25 S3 D22 CZ			Obra	502253220403	189C	27-11-2014	28	8189	671,85	29,86
70DB	30-10-2014	10:57	100	C20/25 S3 D22 CZ			Obra	502253220403	189C	27-11-2014	28	8102	634,95	28,22

Figure 2.2. Excel file with compressive strength results from fresh concrete samples

Usually the concrete is already on a wheelbarrow and properly mixed as the slump test is performed on a portion of the same sample. The moulds used are made of polyurethane. There are moulds made of steel but they are too bulky and heavy to transport to construction sites.

The concrete is scooped into the moulds in two layers. The last layer should overcome the cube mould in such a way that after compacting the concrete never drops below the cube entrance. Each layer is compacted using a needle vibrator for a few seconds. The excess of concrete is removed and the surface smoothed with a trowel. The sample numbered and the small ID card also includes the date and customer name or the designation of the construction site/ project.

The moulds are stored in the construction site or in the production plant for the next 24 to 48 hours before being taken to the laboratory. The cubes are removed from the moulds with compressed air and then submerged on the curing tanks where they stay until they are 7 and 28 days old.

According to NP EN 206-1:2007, during the curing process the cubes must be stored on a chamber with 95% moisture at a temperature of $20 \pm 2^{\circ}\text{C}$ or submerged in water at $20 \pm 2^{\circ}\text{C}$. The water temperature is measured and registered once a day using a metal immersion type thermometer. To maintain the temperature stable at all times, water tanks include thermostats.

The moulds are cleaned, lightly coated with a mould release agent and stored until the next use.

At the day of testing, the cubes are removed from the tanks and the excess of moisture is wiped from the surface. Before the compression test, the weight of the cubes is registered and they are measured to make sure the dimensions are inside the tolerance stated in NP EN 12390-1.

The cubes are placed one at a time in the testing machine, with the load being applied perpendicularly to the cast surface. The identification and details of the sample are inserted into the software of the testing machine to generate the report after the test. A constant 1 MPa/s load is applied until failure occurs (Figure 2.3). The computer registers the evolution and the compressive strength of the cube. The report usually includes all the cubes from the same sample, only one when 7 days old and three when 28 days old.



Figure 2.3. Example of cube sample after failure occurs

From a quality assessment stand point, the results must be compliant with both criterion from Table 2.5.

Table 2.5. Identity criteria for compressive strength (NP EN 206-1:2007)

Number n of test results for compressive strength from the defined volume of concrete	Criterion 1	Criterion 2
	Mean of n results (f_{cm}) N/mm ²	Any individual test result (f_{ci}) N/mm ²
1	Not applicable	$\geq f_{ck} - 4$
2 - 4	$\geq f_{ck} + 1$	$\geq f_{ck} - 4$
5 - 6	$\geq f_{ck} + 2$	$\geq f_{ck} - 4$

Samples from different concrete families count as individual test results. On the other hand, samples from the same concrete family add up to the number of test results. For example, during the initial inspection the accreditation body takes three

samples from different concrete families, the applicable conditions are the ones stated for $n = 1$. In case the three samples are taken from the same family, the conditions for $n = 3$ must be respected.

2.2. WORKS DEVELOPED DURING THE INTERNSHIP

2.2.1. Setup the laboratory

To start off the certification process it was required to setup the laboratory where tests would be performed. SPRAL's laboratory has all the equipment necessary to test fresh and hardened concrete, aggregates and to test new compositions on a laboratory scale. All the test instruments are verified by APEB - *Associação Portuguesa das Empresas de Betão Pronto* for conformity. Water tanks used to store the samples for the curing process, need to be adjusted to maintain a constant temperature of $20^{\circ}\text{C} \pm 2^{\circ}\text{C}$, according to NP EN 12390-2:2009. The storage capability had to be expanded to meet the sample and testing schedule planned (Figure 2.4).

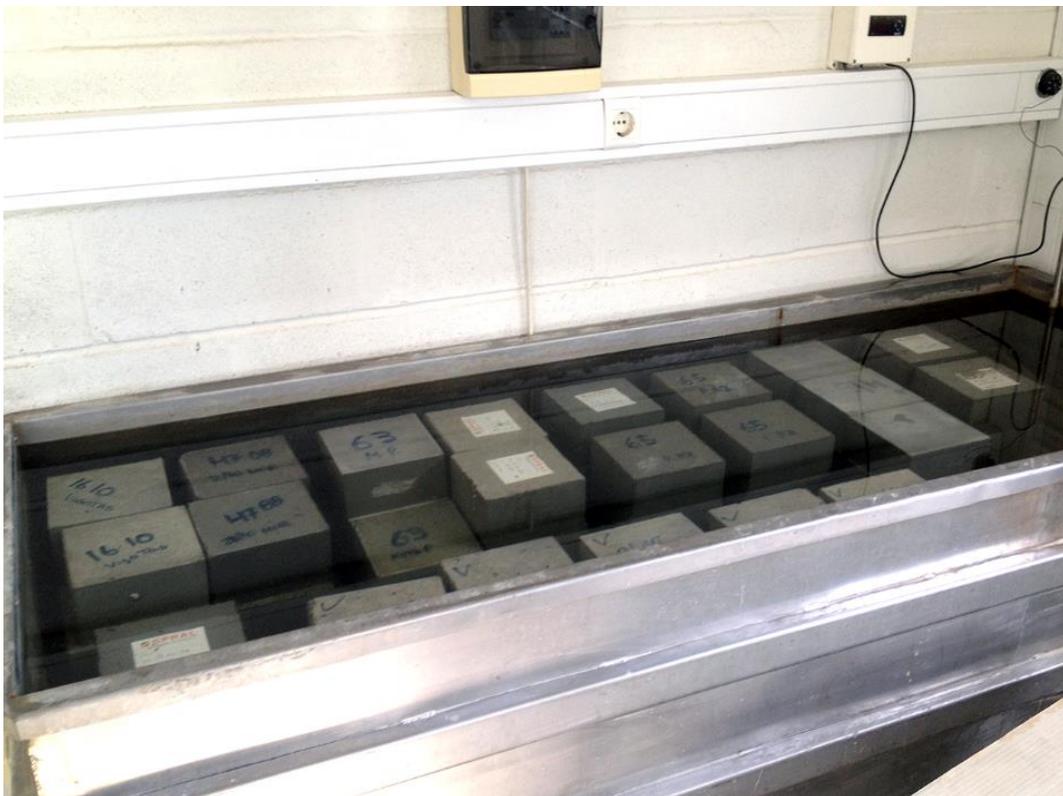


Figure 2.4. Cubic samples during the curing process

All new forms were created for the new daily measurements and tests needed to have the production plant working in compliance with NP EN 206-1:2007.

2.2.2. Initial test to collect data

Measure concrete consistency using the slump test, according to NP EN 12350-2 and EN 206-1:2007:A. The slump test was performed for the various families, both at the production plant and on site in order to understand the influence of the adjuvants and transportation.

Test cube samples from different families at various ages, according to NP EN 12390-3, and study previous results to create the concrete families.

With these results it was possible to evaluate the fresh concrete performance and production process, using two criterion of the NP EN 206-1:2007 standard, conformity control for compressive strength (Table 2.4) and conformity criteria for consistency (Table 2.2).

In terms of resistance, the results from the initial testing were very positive. In fact, when tested at 7 days, the resistance would be, most of the times, above the minimum resistance for that specific family at 28 days. When tested at 28 days, the resistance would sometimes meet the minimum for the next class of resistance.

According to initial performance evaluation, there were some adjustments to be made at the concrete composition level.

Some families had clearly too much cement, other families needed adjustments on water quantity and percentage of adjuvants to better accommodate differences due transportation. A meeting with a technical representative from *Sika Portugal, SA* proved to be very helpful to a better use of *Sika* adjuvants and also to fine-tune concrete compositions using their proprietary software, *SikaComp 2.5* (Figure 2.5), developed in 2007 in compliance with the European standards.

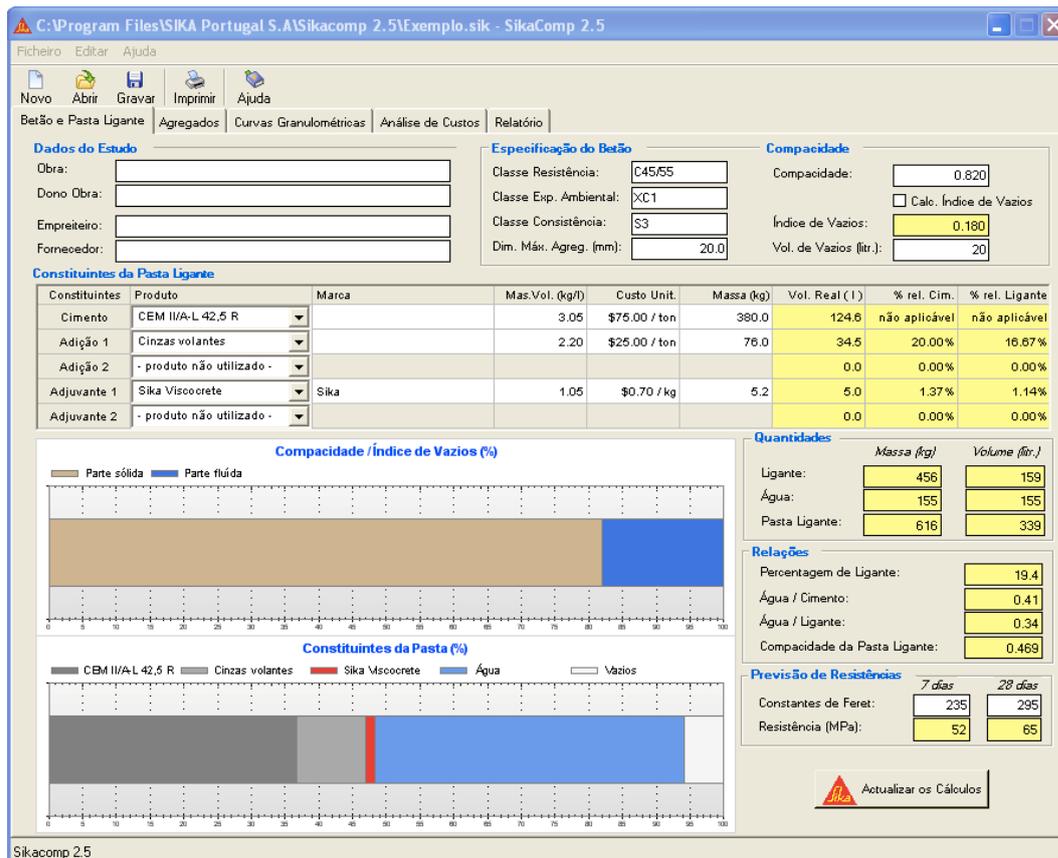


Figure 2.5. SikaComp 2.5 software with composition example

Before using of this software, the aggregates used in the fresh concrete production plant were studied in terms of size distribution using sieve analysis.

With this analysis it was found that two of the aggregates used were too similar for *SikaComp 2.5* to work with.

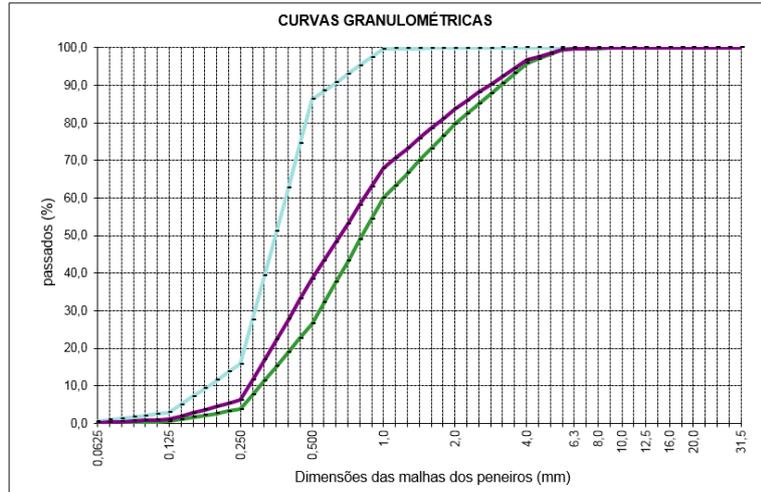
It was needed to combine both and use the result as a single aggregate. Sika representative provided the *Excel* file to perform this additional step (Figure 2.6).

Mistura de areias

Volume absoluto dos agregados: 674 litros

Estudo de uma pré-mistura das areias na composição do betão

Módulo	malha (mm)	Areia		Mistura
		Areia fina	Areia grossa	
		proporções		
		0,20	0,80	
36	0,0625	0,5	0,1	0,2
42	0,125	2,8	0,5	1,0
48	0,250	15,8	3,7	6,1
54	0,500	86,2	26,5	38,4
60	1,0	99,7	60,0	67,9
66	2,0	99,9	79,7	83,7
72	4,0	100,0	95,8	96,6
75	5,6	100,0	99,4	99,5
76	6,3	100,0	99,7	99,8
78	8,0	100,0	99,8	99,8
80	10,0	100,0	100,0	100,0
81	11,2	100,0	100,0	100,0
82	12,5	100,0	100,0	100,0
83	14,0	100,0	100,0	100,0
84	16,0	100,0	100,0	100,0
86	20,0	100,0	100,0	100,0
87	22,4	100,0	100,0	100,0
90	31,5	100,0	100,0	100,0
mod. fin.:		1,95	3,34	3,06



Constituintes da mistura	Massa Vol. Real	Proporções		Massas
Areia fina	2,59 kg/l	0,474	0,095	165 kg
Areia grossa	2,63 kg/l		0,379	672 kg

Figure 2.6. Combining two aggregates

2.2.3. Monitoring on the construction site

SPRAL is providing fresh concrete to customers in a 50 km radius from the production plant. SPRAL provides fresh concrete for the structural elements: foundations, slabs and columns. Some other works include foundation piles and sea walls, related with the regional preservation and improvement plans of iconic *Ria de Aveiro*.

It is important to monitor the delivery of fresh concrete (Figure 2.7) as often as possible, not only for visual inspection, consistency test and sampling but also to guarantee there is no additional re-mixture or if needed, it is all done under controlled conditions under the responsibility of the producer.



Figure 2.7. On site monitoring

2.2.4. Daily sampling and testing

Part of having a certification for fresh concrete production according to NP EN 206-1:2007 and also the standard ISO 9001:2000 for quality manager system, involves a continuous sampling and testing plan, to assess quality and control of the production process.

This plan is set according to Table 2.4. NP EN 12350-1 defines the rules of the sampling process. Fresh concrete testing is done with the slump test, according to NP EN 12350-2 and as explained in 2.1.2.1. To test hardened concrete, NP EN 12390 establishes every details, most relevant parts are Part 1: Shape, dimensions and other requirements for test specimens and moulds, Part 2: Making and curing specimens for strength tests as well as Part 3: Compressive strength of test specimens. The process was explained in detail in 2.1.2.2.

There was also the need to better organise the testing plan, so the existent file with all the sample information was upgraded.

The number and level of detail of reports increased. Initially the results were registered by hand but now include detailed information from the compressive strength test, such as the evolution of the force applied during the test, combine multiple samples on the same report, using the compressive strength test equipment to its maximum potential and providing customers and quality control director with much more reliable information.

Taking advantage of a calendar app synchronized between all the staff (Figure 2.8), the tests at 7 or 28 days of age were always done on time with a morning notification regarding which tests needed to be completed that day.

	dom	seg	ter	qua	qui	sex	sáb
11	15	16	17	18	19	20	21
		Ensaio 4 dias 7aa, 7ba Ensaio 3 dias 8AA 8BA	Ensaio 3 dias 9AA 9BA	Ensaio 100 28dias Ensaio 28 dias vigas pr...	Ensaio 3dias 10AA 10BA Ensaio 28dias 102	Ensaio 3dias 11AA	Ensaio 3dias 12AA
12	22	23	24	25	26	27	28
		Ensaio 4 dias 13AA	Ensaio 7dias 106	Ensaio 103 28dias		Ensaio 101 28dias Ensaio 3dias 17AA BA	
13	29	30	31	1/04	2	3	4
		Ensaio 28dias 1da	Ensaio 28dias 2ca, 2da Ensaio 28dias 105	Ensaio 28dias 3ba, 3c... Ensaio 7dias 18AA BA	Ensaio 7dias 19AA	Ensaio 104 28dias Ensaio 27dias 4ca, 4da	
14	5	6	7	8	9	10	11
		Ensaio 28dias 5ca, 5da	Ensaio 28dias 6ca, 6da	Ensaio 7dias 107AB BB	Ensaio 28dias 7ca, 7da Ensaio 7dias 21aa	Ensaio 28dias 8CA 8DA Ensaio 27dias 9CA 9DA Ensaio 3dias 22aa	
15	12	13	14	15	16	17	18
		Ensaio 28dias 10CA 10...	Ensaio 28dias 106 Ensaio 28dias 11CA	Ensaio 28dias 12AA B... Ensaio 7dias 108AB	Ensaio 28dias 13CA DA Ensaio 7dias 109AB BB Ensaio 3dias 23Aa	Ensaio 28dias 14AA B... Ensaio 27dias 15CA DA	
16	19	20	21	22	23	24	25
		Ensaio 28dias 16CA DA	Ensaio 28dias 17CA DA	Ensaio 28dias 18CA DA	Ensaio 28dias 19BA DA		

Figure 2.8. Calendar app with dates for compressive strength tests

2.2.5. Concrete production

An important part of the production is obviously to manage the production plant itself, component stocks, trucks, drivers and orders. First step was to learn to operate the production system to produce each concrete composition on automatic mode or if there is any factor that should be accounted, like different gravel or water quantities, change the system to manual and adjust what is needed (Figure 2.9). According to NP EN 206-1:2007, training of the staff and written documents with all

the procedures are mandatory to achieve production certification.



Figure 2.9. Fresh concrete production control systems

Chapter 3

OTHER ACTIVITIES

3. OTHER ACTIVITES

3.1. LABORATORY

Starting in October, under the technical guidance of Eng. Paulo and Eng. José Rebelo. These activities lasted the entire period of internship.

3.1.1. Sieve analysis for external services

Companies in the business of extraction of sand and aggregates used in construction hire SPRAL for laboratory works. Companies which products have CE Marking get audited regularly to maintain product quality. These companies collect samples on a weekly basis and deliver them to SPRAL for laboratory testing and report (Figure 3.1).



Figure 3.1. Example of the aggregates tested

The sieving method is used to determine the particle size distribution according to EN 933-1.

A sample is taken from a batch of each aggregate. To get a representative sample from large batches, manual quartering is a technique that involves mixing the material, building a cone with it, flattening the surface and divide in four quarters. The sample is the material from two opposite quarters. This technique can be applied multiple times until the sample size is adequate.

The sample is not washed, only dried at 110°C until it reaches constant mass. After the sample is back to room temperature, it is weighted and then poured into the sieving column (Figure 3.2).

The column is mechanically shaken for a pre-set time of 14 minutes. When finished, the sieves are removed one at a time, making sure all the material which passes the sieve is left on the next one.



Figure 3.2. Laboratory for sieve analysis

The material retained on each sieve is weighted and the mass is registered. The total mass must be within the range of 1% difference from the mass of the sample prior to sieving method.

This data is then transformed to a cumulative percentage of material passing each

sieve and presented in a table, in a curve or both.

3.1.2. Colour study for split blocks

SPRAL produces split blocks in a variety of colours. In some special orders, it is possible to produce blocks with a colour requested by the customer.

To meet the requirements, various samples are created with subtle colour differences. The starting point for a new colour is the composition for 1 m³ with the most similar colour. Then scale it down to small 0,05 x 0,05 x 0,05 meters samples (Figure 3.3) and produce a spectrum of colours around the original one.



Figure 3.3. Colour study samples

When the customer decides on the colour, that composition is scaled back to 1 m³ and the production starts.

3.1.3. Quality control of precast and prestressed production plants

Having CE Marking requires regular sampling and testing to validate the production process and maintain the product quality. This includes following a sampling schedule that needs to be kept. Concrete families used in prestressed beams and hollow-core slabs are tested for compression strength test at 28 days of age.

During the internship period, the production of heavy duty precast products required increasingly more tests. This meant the resources allocation had to be adjusted, slowing down the study of fresh concrete production and ramp up the quality control over the other production plant. At this plant, the cube samples are very important because massive concrete parts need to be moved quickly and the design requires a minimum compression strength value to do so (Figure 3.4). Usually four cubes are produced per sample. The compression test could be performed as early as 24 hours and 48 hours or regular periods as 3 days, 7 days and always at 28 days.



Figure 3.4. Precast concrete panels

3.2. SOFTWARE DEVELOPMENT

This chapter describes the software tools developed during the internship. Both solutions are very practical and commercially oriented.

The *Excel* add-in was developed using *C#* and the *AutoCAD* plugin developed using *VB.NET*. *VB.NET* was used because of the lack of documentation on how to use *AutoCAD* API with *C#*.

Both programming languages are developed by Microsoft and take advantage of the .NET framework, its libraries and runtime. Every step from programming to deployment can be done using the same software, *Visual Studio*.

The most recent programming languages are object oriented, meaning, the program is focused on objects, its methods and attributes, and the interaction between different objects. This paradigm includes encapsulation, inheritance and polymorphism (Albahari and Albahari, 2012). Procedure languages are interested on the routines needed to solve any given task.

A class is a conceptual representation, a template of “something” and it’s made up of different pieces of data (Albahari and Albahari, 2012). The real life counterpart of a class in object oriented programming could be a blueprint of a house. That “something” is an object, for example, the house itself, as it is an instance of that class.

Encapsulation is one of the key properties of this type of programming and the idea is to build walls around the code hiding the implementation from other parts of the code or even from third party users (Albahari and Albahari, 2012). A real life representation could be when knocking on the door of a neighbour to ask for salt, the interaction is made through windows or doors but the location where our neighbour stores the salt inside his house is still unknown.

Inheritance is a mechanism to reuse code. An object or class can be based on other object or class, having the same behaviour or attributes of the next level in the hierarchy (Albahari and Albahari, 2012). For example a class “person” with “name” and “age” as attributes that can be reused when creating a class “worker” that adds the attributes of “job” and “years of service”, inheriting the name and age from the

parent class.

Polymorphism is somewhat related to inheritance and it allows a class or an object to appear to be a different type. Using the previous example, it is possible to refer to the class “worker” as the base class or interact with the parent class of that one. This form of polymorphism and others available allow great flexibility.

The syntax is the most noticeable difference between *C#* and *VB.NET* but both are very simple and easy to understand. The software tools developed work only on Windows operating systems and are compatible with Windows 7 and above, although both languages allow to develop software for Mac and mobile devices. The *Excel* add-in works on top of *Microsoft Office Excel* and it is compatible with the last four versions of this software suite. The *AutoCAD* plugin works on top of *Autodesk AutoCAD* and it is only compatible with the versions 2015 and 2016.

The development started in January and exceed the internship period.

3.2.1. Excel Add-in

The process of budgeting for what is called light weight precast products is very exhaustive and done by hand. It includes products for rib and block slabs, beams for roof support systems and hollow-core slabs.

There were some old *Excel* files that were not working anymore but had been created to help improve the productivity issue regarding this process. It was quickly noticed that the files were using very basic formulas and in the end were not giving any advantage to people at the office other than save some paper.

Brief description of the designing process

A new project and blueprint arrives via e-mail or is handed by a sales person. The operator takes note of every measure and calculates the areas one by one, by hand or using a basic calculator and writes them on a paper sheet, identifying each slab by a number or combination of numbers and letters. Then reads the project details to understand what kind of loads need to be considered and what kind of restrictions exist. Opens SPRAL’s software to calculate the rib and block slab or hollow-core slab, fills in all the information like span of each slab, variable and permanent loads, restrictions, etc. Prior to this internship this process of calculation most of the times

was done by hand because the software was not working on Windows versions after XP. After getting the results, the designer:

- Writes down what type of rib and block slab will be used in each slab.
- By hand, calculates the total area for each type of slab needed per floor.
- Checks a table with information about how much percentage of a truck load is occupied by one square meter of each type of slab needed.
- Calculates a rough estimative of how many trucks are needed and calculates the price based on the travel distance, information that is also available on a table.
- Opens the invoicing software, inserts all the data and finally gets the quotation.

This process not only takes a lot of time but also it is very susceptible to error due to all the handmade calculations and copying information from and to different supports multiple times to finish one task. The result of this process for rib and block slab can be and hollow-core slab can be found in annex B and C, respectively.

A new *Excel* file with custom made add-in has been proposed. The idea was to solve the budgeting question and also plan transportation. With only one *excel* file and only requiring the core information of the project e.g. dimensions, loads and restrictions it would be possible to provide an accurate solution consuming a lot less time and providing the optimal solution in terms of price because the table of prices for each type of slab is used as one of the attributes. At its first iteration, it will only solve simply supported slabs with no concentrated loads for both rib and block slabs and hollow-core slabs.

3.2.1.1. Excel for rib and block slabs

Rib and block slab is a very popular solution in Portugal, suitable for small span slabs and not so heavy loads. SPRAL has to answer to dozens of quotation requests every day and it goes from one storey to eight storey buildings.

The first step was to gather all the data available, document approval of all types of rib and block slabs, prices of each product, distance of each city to the production plant, details of the truck loads and capacity.

INSERIR / PODE EDITAR			DIMENSIONAMENTO										DIMENSIONAMENTO ARMADURAS										Tipo de Pavimento
Laje	Vão de Cálculo	Espessura da Laje	Msd	Vsd	Mfct	EI	flacha inst. cm	flacha longo prax	flacha max mm	Maciçamento	Nº tarugos	Armadura Tarugos	Armadura Distrib	φ									
Exemplo	6.10	28	3.55	55.43	86.35	32.08	28429	0.53	1.08	1.5	0.10	3.268	AR 42	508 c/ 0.9	84-33025-28								
L1a	4.40	16	2.31	24.79	22.54	13.70	4991	0.55	1.01	1.1	0.25	2.268	AR 38	508 c/ 0.7	83-33012-16								
L2	7.00	30	4.52	81.02	46.29	48.20	36376	0.68	1.45	1.5	0.00	3.268	AR 50	508 c/ 1.1	84-22425-30								
L3	4.50	16	2.31	25.93	23.05	14.33	4991	0.61	1.10	1.125	0.30	2.268	AR 38	508 c/ 0.7	83-33012-16								
L4	7.00	30	4.52	81.02	46.29	48.20	36376	0.68	1.45	1.5	0.00	3.268	AR 50	508 c/ 1.1	84-22425-30								
L5	3.10	13	1.97	11.75	15.17	6.39	2473	0.26	0.45	0.775	0.15	1.268	AR 30	508 c/ 0.5	82-40009-13								

Resultados dos Cálculos:																									
Vão	Laje Tipo	Espeçura	P. Póçpio	Msd	(Apoio Esq.)	Msd	(Apoio Dir.)	Msd	(Vão)	Mfct	(Vão)	Vsd	(Apoio Esq.)	Vsd	(Apoio Dir.)	flacha Inst.	flacha Long. Prazo	flacha admisi vel	Maciçamento Esq.	Maciçamento Dir.	Nº de Tarugos	Arm. tarugos	Arm. Distribuição	Arm. Negativa no Apoio	Arm. Negativa no Apoio
(m)		(cm)	(kN/m ²)	(kN.m/m)	(kN.m/m)	(kN.m/m)	(kN.m/m)	(kN.m/m)	(kN.m/m)	(kN/m)	(kN/m)	(kN/m)	(kN/m)	(kN/m)	(kN/m)	(cm)	(cm)	(cm)	(m)	(m)				Esq.	Dir.
L1A	6.10	B48L33x25-28	28	3.55	0.00	0.00	55.43	32.09	36.35	36.35	-36.35	0.53	1.08	1.01	0.10	0.10	1.5	0.25	0.10	0.10	3	208	AR42	508/m c/0.90m	508/m c/0.90m
L1B	4.40	B48L33x12-16	16	2.31	0.00	0.00	24.79	13.70	22.54	22.54	-22.54	0.55	1.01	0.25	0.25	0.25	1.1	0.25	0.25	0.25	2	208	AR38	508/m c/0.70m	508/m c/0.70m
L2	7.00	B48L22x25-30	30	4.52	0.00	0.00	81.02	48.20	46.29	46.29	-46.29	0.68	1.45	0.00	0.00	0.00	1.5	0.00	0.00	0.00	3	208	AR50	508/m c/1.10m	508/m c/1.10m
L3	4.50	B48L33x12-16	16	2.31	0.00	0.00	25.93	14.33	23.05	23.05	-23.05	0.61	1.10	0.30	0.30	0.30	1.125	0.30	0.30	0.30	3	208	AR38	508/m c/0.70m	508/m c/0.70m
L4	7.00	B48L22x25-30	30	4.52	0.00	0.00	81.02	48.20	46.29	46.29	-46.29	0.68	1.45	0.00	0.00	0.00	1.5	0.00	0.00	0.00	3	208	AR50	508/m c/1.10m	508/m c/1.10m
L5	3.10	B24L40x09-13	13	1.97	0.00	0.00	11.75	6.39	15.17	15.17	-15.17	0.26	0.45	0.20	0.20	0.20	0.775	0.20	0.20	0.20	1	208	AR30	508/m c/0.50m	508/m c/0.50m

Figure 3.5. Results comparison between the solution under development and the software in use

The design was very tricky. The initial goal was to reach the same results as the current software and there was no documentation regarding the software. It was only assumed the software followed REBAP rules and premises and it required a process of reverse engineering to match the results.

After many iterations the results were satisfactory (Figure 3.5) but it was unclear which criterion the software used to select the best solution. Exhaustive tests proved that it was not use an economic criterion.

The original software, allows n to vary between 8 and 24 on the calculation of bending moment, being n dependent of the position of the slab. For simply supported slabs, anything above 11 is out of the recommended safety limits (Cachim, 2012).

Other differences include a safety coefficient of 1,35 for self-weight and 1,5 for everything else, other permanent loads and variable loads. Even the self-weight is set to 1,5 as the default value.

The original software verification of the maximum deflection was $Span/400$ while actual standards recommend $Span/250$.

The original software uses the safety coefficient of 1,35 for the self-weight and a safety coefficient of 1,5 for other permanent loads and all variable loads.

For a more future proof solution, Eurocode was used as the standard for calculations on the final version.

To get both the design results shown in Figure 3.5 took only a couple of minutes, but the original software only gives information about which type of slab to use. The Excel solution developed, in the same amount of time and requiring the same effort provides the complete budget, including type of slabs, quantities, prices and transportation.

INSERIR / PODE EDITAR

Laje	Vão de Cálculo	A encher	Espessura da Laje	Posição	Tipo de Utilização	Sobrecarga	Psi2	Revestimentos	Divisórias	Verificar Flecha	
										L/250	outra
Piso 0											
L1a	6,10	3,8		Isolada	Escritórios	3	0,6	alcatifa+estruque	1	0,48	Sim
L1b	4,40	4,6		Isolada	Escritórios	3	0,6	alcatifa+estruque	1	0,48	Sim
L2	7,00	8,8		Isolada	Restaurantes/Cafés	6	0,6	Azulejo+assentamento	2	0,55	Sim
L3	4,50	8,8		Isolada	Restaurantes/Cafés	4	0,6	Azulejo+assentamento	2	0,55	Sim
L4	7,00	2		Isolada	Habituação	2	0,3	taco+estruque	1,5	0,66	Sim
L5	3,10	9,2		Isolada	Habituação	2	0,3	taco+estruque	1,5	0,66	Sim
L6	3,80	8,5		Isolada	Habituação	2	0,3	taco+estruque	1,5	0,66	Sim
L7	6,50	10		Isolada	Habituação	2	0,3	taco+estruque	1,5	0,66	Sim
L8	5,00	8,5		Isolada	Habituação	2	0,3	taco+estruque	1,5	0,66	Sim
Piso 1											
L1	7,10	2	34	Isolada	Habituação	2	0,3	taco+estruque	1,5	0,66	Sim
L2	6,90	3,1	34	Isolada	Habituação	2	0,3	taco+estruque	1,5	0,66	Sim
L3	7,10	7		Isolada	Habituação	2	0,3	taco+estruque	1,5	0,66	Sim
L4	7,10	6,9		Isolada	Habituação	2	0,3	taco+estruque	1,5	0,66	Sim
L5	6,70	7,1		Isolada	Habituação	2	0,3	taco+estruque	1,5	0,66	Sim
L6	2,40	7,1		Isolada	Habituação	2	0,3	taco+estruque	1,5	0,66	Sim
L7	4,50	9,5		Isolada	Habituação	2	0,3	taco+estruque	1,5	0,66	Sim
L8	5,30	8,7		Isolada	Habituação	2	0,3	taco+estruque	1,5	0,66	Sim

Figure 3.6. Example of input values using a real life scenario with rib and block slabs

This Excel file is divided in two Excel sheets. The first one is related to the design process and the second to budgeting and transportation. The first *Excel* sheet is where the user can insert and edit the details (Figure 3.6), starting by writing a designation for each floor and slab. The second column refers to the span and the third column is the perpendicular dimension, measured on the blueprint. Slabs can have a height restriction or not and the next column can be filled with that information or left blank in case there is no restriction, although it is suggested to respect a relation where the total height of the slab greater than $Span/24$ to prevent excessive deformation (Cachim, 2012).

Then is a dropdown menu to choose the position of the slab. Options available are isolated, internal or external. This will affect the bending moment calculation, using the formula:

$$M_{sd} = \frac{P_{sd} \times L^2}{n} \quad (1)$$

n being (Cachim, 2012):

- 8 when the slab is isolated;
- 9 when is external;
- 10 when is internal.

The following column is a dropdown menu with types of use from Eurocode 1 (Table 3.1). After choosing the type of use, the value of imposed load for general effects from National Annex automatically fills the next column as well as the respective coefficient of reduction from Eurocode 0 on the column that follows.

Table 3.1. Load for general effects EC1 and factor of reduction EC0

	Variable Load (kN/m²)	Ψ₁	Ψ₂
Roofs	0,3	0	0
Non-accessible balconies	1	0	0
Accessible balconies	2	0,5	0,3
Domestic areas	2	0,5	0,3
Office areas	3	0,5	0,6
Restaurants	4	0,7	0,6
Churches	5	0,7	0,6
Sports halls	6	0,7	0,6
Hotels kitchens	4	0,5	0,3
Storage areas	5	0,9	0,8
Light industry workshops	5	0,9	0,8
Private parking garages	4	0,7	0,6
Public parking garages	5	0,5	0,3
Public parking garages for passenger cars	3	0,7	0,6

Next is a dropdown menu with a list of common finishing solutions suggested by SPRAL (Table 3.2). Choosing one from this list automatically fills the next column with the load value for general effects of that finishing. If the dropdown menu is left blank it is possible to manually insert the load value according to the project details.

Table 3.2. General effects load for different finishing solutions

Finishing solutions	G (kN/m²)
Tile	0,55
Terrazzo + insolation	1,25
Terrazzo + sanded	0,85
Terrazzo + plaster	1,20
Timber + plaster	0,66
Timber + sanded	0,85
Carpet + plaster	0,48

Also from the project details comes the load value of walls that needs to be inserted on the next column.

Last step is to set some verifications to limit maximum deflection, $Span/250$, according to Eurocode 2. The other verification is manually set, it is the maximum deflection in centimetres to prevent damage to adjacent elements such as walls. A value frequently used is 1,5 centimetres.

After inserting this information for the first slab, as soon as the user inserts a designation of a new slab, all the information is filled automatically except slab dimensions. A few adjustments might be needed in some slabs. Most of the times all slabs are considered isolated for safety reason, the type of use and finishing are typically the same in the same building and it is also the same verifications wise.

With this information and using the capabilities of C#, it was possible to create an Excel Add-in (Figure 3.7) that determines the best type of rib and block slab for each situation from a list with 191 options available. In general, the program compares the resistant values from the document approval to the design values.

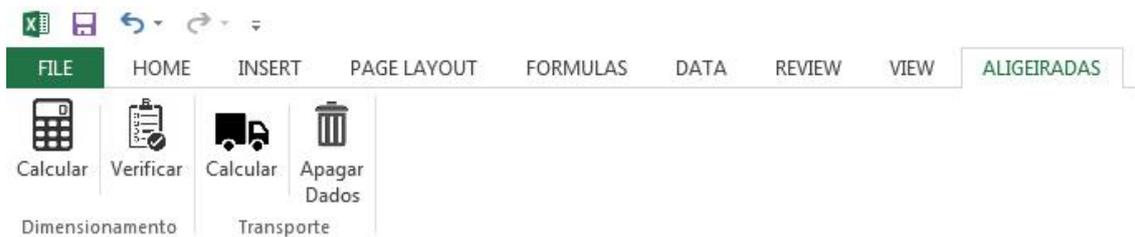


Figure 3.7. Ribbon options for design and transport of rib and block slabs and roof support systems

Design at ULS for bending

First step is to compare M_{rd} to M_{sd} .

$$M_{sd} = \frac{(1,35 \times G + 1,5 \times Q) \times L^2}{n} \quad (2)$$

G being the value of permanent loads; Q being the value of variable loads; n assuming the value of 8, 9 or 10 depending on the slab position as seen in equation (1).

All slab types that do not meet the requirement of M_{rd} equal or superior to M_{sd} are removed from the list of possible solutions.

Design at SLS for bending

Now with a substantially shorter list, it compares the value of M_{fctk} to M_{freq} . M_{freq} being the moment for frequent combination of actions and M_{fctk} the value of moment for which cracks start to appear on the slab.

$$M_{freq} = \frac{(G + \psi_1 \times Q) \times L^2}{n} \quad (3)$$

Slab types that do not respect the condition M_{fctk} equal or superior to M_{freq} are removed from the list of possible solutions.

Design at ULS for shearing

The next step is to compare V_{rd} to V_{ed} , where V_{rd} to V_{ed}

$$V_{ed} = 0,55 \times (1,35 \times G + 1,5 \times Q) \times L \quad (4)$$

There is an additional verification at this stage. If the distance at which V_{rd} is lower than V_{ed} is less than 0,3 meters, that type of slab can be used with solid ends.

$$D = \frac{V_{ed} - V_{rd}}{P_{sd}} \quad (5)$$

Design at SLS for deformation

Deflection

$$deflection = \frac{5 \times (G + \psi_2 \times Q) \times L^4}{384 \times EI} \quad (6)$$

Long term deflection (Camposinhos e Serra Neves, 2005)

$$d_{lt} = \frac{5 \times (G + \psi_2 \times Q) \times L^4}{384 \times EI} \times \left(1 + \frac{G}{G + \psi_2 \times Q} \times \varphi\right) \quad (7)$$

Where φ is the creep coefficient and assumes a value of 2.

At this stage the list of possible solutions is complete. Before choosing, the software runs the type of slabs on the list against the price list and selects the cheaper per square meter. The next section of the design sheet provides a detailed view on the design parameters (Figure 3.8).

DIMENSIONAMENTO												
L/24	PP	Q	G	Msd	Ved	Mfreq	Ei	flecha inst. (cm)	fluência	flecha longo prazo (cm)	flecha max (mm)	
confirmar	3,78	3	5,26	53,96	38,92	31,44	26748	0,48	2,00	1,18	2,44	
confirmar	2,55	3	4,03	24,06	24,06	13,38	5986	0,48	2,00	1,13	1,76	
confirmar	6,16	6	8,71	127,15	79,92	79,07	74106	0,52	2,00	1,25	2,8	
confirmar	2,73	4	5,28	33,23	32,49	20,45	7548	0,54	2,00	1,29	1,8	
confirmar	5,09	2	7,25	78,32	49,23	44,41	51393	0,48	2,00	1,36	2,8	
confirmar	1,97	2	4,13	10,30	14,62	4,96	2473	0,23	2,00	0,63	1,24	
confirmar	1,91	2	4,07	15,33	17,75	7,35	3697	0,34	2,00	0,94	1,52	
confirmar	4,03	2	6,19	59,98	40,60	32,69	30352	0,52	2,00	1,47	2,6	
confirmar	2,36	2	4,52	28,44	25,03	14,13	7826	0,53	2,00	1,47	2	
ok	5,09	2	7,25	80,58	49,94	45,68	51393	0,51	2,00	1,44	2,84	
ok	5,09	2	7,25	76,10	48,53	43,15	51393	0,45	2,00	1,28	2,76	
confirmar	5,09	2	7,25	80,58	49,94	45,68	51393	0,51	2,00	1,44	2,84	
confirmar	5,09	2	7,25	80,58	49,94	45,68	51393	0,51	2,00	1,44	2,84	
confirmar	4,51	2	6,67	67,36	44,24	37,43	36213	0,53	2,00	1,49	2,68	
confirmar	1,97	2	4,13	6,17	11,32	2,97	2473	0,08	2,00	0,23	0,96	
confirmar	2,31	2	4,47	22,87	22,36	11,31	4991	0,54	2,00	1,50	1,8	
confirmar	2,84	2	5	34,23	28,42	17,56	10917	0,53	2,00	1,47	2,12	

Figure 3.8. Design values of a real life study case for rib and block slabs

The document approval designates how much distribution reinforcement is used on each type of slab. The value is given in cm^2/m but it helps to have the respective value of commercial welded mesh as seen on the table below (Table 3.3).

Table 3.3. Designation and area of commercial welded mesh

Commercial welded mesh		
Designation	A_{long} (cm^2/m)	A_{transv} (cm^2/m)
AR 30	0,71	0,24
AR 34	0,91	0,3
AR 38	1,13	0,38
AR 42	1,39	0,46
AR 46	1,66	0,46
AR 50	1,96	0,46
AR 55	2,38	0,46
AR 60	2,83	0,55
AR 65	3,32	0,65
AR 70	3,85	0,79
AR 76	4,54	0,94
AR 82	5,28	1,11
CQ 30	0,47	0,47
CQ 38	0,76	0,76
AQ 30	0,71	0,71
AQ 38	1,13	1,13
AR 50	1,96	1,96

SPRAL considers transverse beams on slabs with span equal or higher than 2 meters, with a maximum of 2 meters in between.

This transverse beams are reinforced with 10% of the longitudinal area of

distribution reinforcement when calculated for the distance between two consecutive transverse beams, considered 2 meters, using a minimum of two reinforcement bars (Table 3.4).

Table 3.4. Reinforcement of transverse beams

Reinforcement of transv. beams	
Designation	cm ²
2φ8	1,01
2φ10	1,57
2φ12	2,26
2φ16	4,02
3φ16	6,03
2φ20	6,28
3φ20	9,42
2φ25	9,82
3φ25	14,73
4φ25	19,64

$$A_{transverse\ ribs} = A_{S_{long}} \times 0,1 \times 2 \quad (8)$$

Top reinforcement

$$M_{sd} = \frac{(1,35 \times G + 1,5 \times Q) \times L^2}{u} \quad (9)$$

u can assume the value of 16 or 40, the latter if the slab is isolated and the former on other cases (Cachim, 2012). This is a simplified and safe approach.

$$\mu = \frac{M_{sd}}{b \times d^2 \times f_{cd}} \quad (10)$$

$$\omega = 0,973 \times (1 - \sqrt{1 - 2,056 \times \mu}) \quad (11)$$

$$A_s = \frac{\omega \times b \times d \times f_{cd}}{f_{yd}} \quad (12)$$

Where d is the height of the slab minus 0,05 meters of cover to reinforcement and b is 1 meter. This gives the area in cm^2/m but the result is presented using the area and designation from the column d in the table below (Table 3.5).

Table 3.5. Top reinforcement

Top reinforcement	
Designation	cm^2/m
5 ϕ 8	2,51
5 ϕ 10	3,93
4 ϕ 12	4,52
5 ϕ 12	5,65
6 ϕ 12	6,79
7 ϕ 12	7,92
8 ϕ 12	9,05
9 ϕ 12	10,08
10 ϕ 12	11,3

The length of these reinforcement bars is a percentage of the span and depends on the slab position. To simplify it was considered to be 15% of the largest adjacent span, to each side.

The result is displayed in the next section, with detailed information regarding reinforcement, transverse beams and solid ends (Figure 3.9).

DIMENSIONAMENTO ARMADURAS				
Maciçamento	Nº tarugos	Armadura Tarugos	Armadura Distribuição	Armadura superior
0,20	3	2φ8	AR 38	5φ8 c/ 0,9
0,25	2	2φ8	AR 38	5φ8 c/ 0,7
0,00	3	2φ8	AR 50	5φ8 c/ 1,1
0,10	2	2φ8	AR 46	5φ8 c/ 0,7
0,00	3	2φ8	AR 38	5φ8 c/ 1,1
0,15	1	2φ8	AR 30	5φ8 c/ 0,5
0,30	1	2φ8	AR 34	5φ8 c/ 0,6
0,25	3	2φ8	AR 42	5φ8 c/ 1,0
0,25	2	2φ8	AR 38	5φ8 c/ 0,8
0,00	3	2φ8	AR 38	5φ8 c/ 1,1
0,00	3	2φ8	AR 38	5φ8 c/ 1,0
0,00	3	2φ8	AR 38	5φ8 c/ 1,1
0,00	3	2φ8	AR 38	5φ8 c/ 1,1
0,00	3	2φ8	AR 42	5φ8 c/ 1,0
0,00	1	2φ8	AR 30	5φ8 c/ 0,4
0,25	2	2φ8	AR 38	5φ8 c/ 0,7
0,30	2	2φ8	AR 38	5φ8 c/ 0,8

Figure 3.9. Design values of reinforcement and solid ends

After these calculations, the software prints the best type of slab for each situation (Figure 3.10). If the operator needs a specific type of slab, he can manually change the name of the slab and the height of the slab. The button “Verificar” does all the calculations and verifications to determine if it is possible or not to use the designated type of slab. If the slab it is not suitable for the situation, an error message will appear on the next column.

VERIFICAÇÃO									
Últimos					Fendilhação			deformação	
MRD	verif.	VRD	verif.	MFCTK	verif.	flecha máxima	verif		
54,2	1	36,7	0	36,8	1	1,5	1		
28,3	1	21,6	0	15,9	1	1,5	1		
128,1	1	96,2	1	87,8	1	1,5	1		
38,6	1	31,4	0	21,4	1	1,5	1		
85,2	1	57,6	1	59,1	1	1,5	1		
12,2	1	13,7	0	6,8	1	1,24	1		
20,9	1	15,3	0	11,4	1	1,5	1		
69,7	1	38,1	0	42	1	1,5	1		
32,6	1	23,1	0	19,3	1	1,5	1		
85,2	1	57,6	1	59,1	1	1,5	1		
85,2	1	57,6	1	59,1	1	1,5	1		
85,2	1	57,6	1	59,1	1	1,5	1		
85,2	1	57,6	1	59,1	1	1,5	1		
73,8	1	50,4	1	49,7	1	1,5	1		
12,2	1	13,7	1	6,8	1	0,96	1		
26,1	1	20,2	0	14,4	1	1,5	1		
36,9	1	25,9	0	22,6	1	1,5	1		

Tipo de Pavimento
B3-33x25-29
B3-33x12-17
283-22x30-35
283-40x12-17
B3-22x30-34
B2-40x09-13
B3-40x12-15
B4-33x25-30
B3-33x16-19
B3-22x30-34
B3-22x30-34
B3-22x30-34
B3-22x30-34
B3-22x25-30
B2-40x09-13
B3-33x12-16
B3-33x16-21

Figure 3.10. Safety verifications and best product for each slab

The next *Excel* sheet starts by importing the most essential information from design sheet. Then it calculates the area of each slab and provides detailed information about the materials divided by type of slab.

If the roof is built with concrete rafters and battens, the information should be added below the last slab details. The rafters are divided in three types depending on the length. The length of the battens is connected to the type and length of rafters used.

Pressing the button “Calcular” on the transportation side of the ribbon, it determines the total quantity of each type of slab per storey and calculates the price of material and delivery.

The user has the ability to further customize the delivery according to customer needs or product availability. It is possible to take care of each storey separately or combine multiple storeys (Figure 3.11). It is often preferable to combine the material for the last storey and the roof support system in one transportation service.

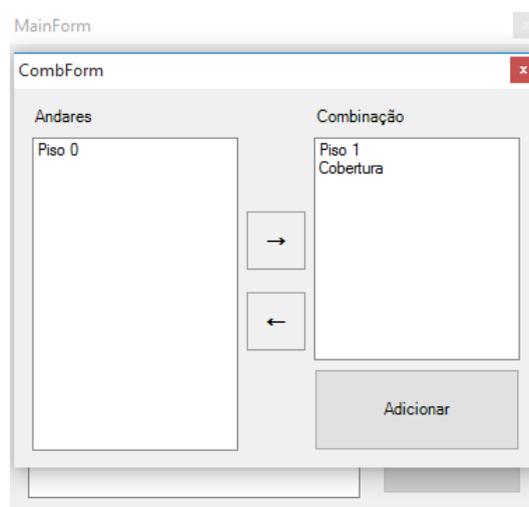


Figure 3.11. Option to combine different storeys in one transport

It is also possible to choose what kind of trucks to use (Figure 3.12). By default the program optimizes the delivery using a combination of trucks with 25 Ton and 15 Ton capacity. The user can select to use only one type of those trucks and also use 15 Ton trucks with integrated crane. Usually this is based on customer needs or construction site limitations but it also allows for a smarter use of *Mario Almeida Transportes*' trucks.

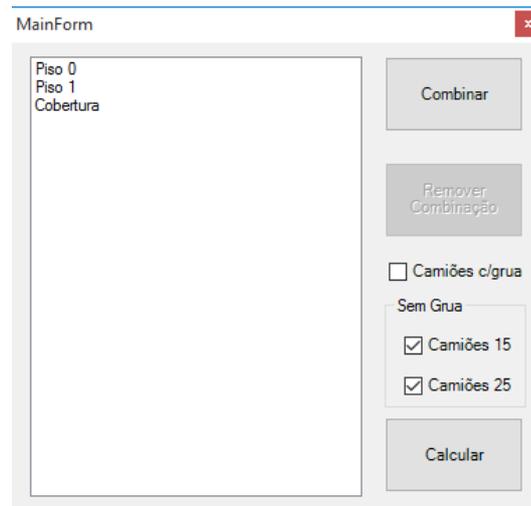


Figure 3.12. Types of trucks to use in this transport

To determine how many trucks are needed, what type and how many square meters travel in each one, the add-in refers to a table with information on the percentage of a truck load occupied to transport one square meter of each type of slab.

The final cost and the details of transportation are added to the Excel sheet. The structure was configured to match the invoicing software structure allowing for an easy and effortless way to create a proposal with the final price and all the details about products and transportation services (Figure 3.13).

This new *Excel* file working together with the add-in, it is a powerful tool to solve any design and budgeting request in a short period of time, using only basic information from the project and with very simple input. It works for rib and block slabs and also roof support systems.

This example took five minutes to complete. Doing the same, by hand, takes more than thirty minutes, even considering an experienced designer and this time discrepancy escalates with the number of slabs and storeys.

Local da Obra: Viana do Castelo 15 Preço custo: 25 Margem comercial % Preço de venda: € Preço de venda: € Preço de venda: €

Observações:

Medida Mtd

ORÇAMENTO

Laje	Vão de Cálculo	A encher	Tipo de laje	Quantidade Parcial	TOTAL POR PISO				TOTAL				TRANSPORTE		Custo global		
					ID	Tipo	Quantidades	Peso	Preço do Material	Tipo	Quantidades	Peso	Preço do Material	15 T		25 T	Preço
Piso 0																	
L1a	6,10	3,80	B3-33x25	23,18 m2	B3-33x25	23,18	3453,82	B3-33x25	23,18	m2	3454	€	€	€	€	€	€
L1b	4,40	4,60	B3-33x12	20,24 m2	B3-33x12	20,24	2226,40	B3-33x12	62,99	m2	6929	€	€	€	€	€	€
L2	7,00	8,80	B3-33x12	61,60 m2	B3-33x12	61,60	10225,60	B3-33x12	102,26	m2	10226	€	€	€	€	€	€
L3	4,50	8,80	B3-33x12	39,60 m2	B3-33x12	39,60	3960,00	B3-33x12	39,60	m2	3960	€	€	€	€	€	€
L4	7,00	2,00	B3-33x12	14,00 m2	B3-33x12	14,00	2366,00	B3-33x12	148,28	m2	25059	€	€	€	€	€	€
L5	3,10	9,20	B3-33x12	28,52 m2	B3-33x12	28,52	2737,92	B3-33x12	45,56	m2	4374	€	€	€	€	€	€
L6	3,80	8,50	B3-33x12	32,30 m2	B3-33x12	32,30	3230,00	B3-33x12	65,00	m2	9685	€	€	€	€	€	€
L7	6,50	10,00	B3-33x12	65,00 m2	B3-33x12	65,00	9685,00	B3-33x12	88,61	m2	10988	€	€	€	€	€	€
L8	5,00	8,50	B3-33x12	42,50 m2	Transporte	1,00	5270,00	B3-33x12	47,57	m2	6993	€	€	€	€	€	€
Piso 1																	
L1	7,10	2,00	B3-22x30	14,20 m2	B3-22x30	14,20	22693,32	B3-22x30	134,28	m2	135	€	€	€	€	€	€
L2	6,90	3,10	B3-22x30	21,39 m2	B3-22x30	21,39	6992,79	B3-22x30	118,70	m2	600	€	€	€	€	€	€
L3	7,10	7,00	B3-22x30	49,70 m2	B3-22x30	49,70	1655,84	B3-22x30	118,70	m2	600	€	€	€	€	€	€
L4	7,10	6,90	B3-22x30	48,99 m2	B3-22x30	48,99	4702,50	B3-22x30	18,20	m	109	€	€	€	€	€	€
L5	6,70	7,10	B3-22x30	47,57 m2	B3-22x30	47,57	5717,64	B3-22x30	21,60	m	130	€	€	€	€	€	€
L6	2,40	7,10	B3-22x30	17,04 m2	B3-22x30	17,04	540,00	B3-22x30	41,00	m	246	€	€	€	€	€	€
L7	4,50	9,50	B3-22x30	42,75 m2	B3-22x30	42,75	2208,00	B3-22x30	11,00	Pcs	500	€	€	€	€	€	€
L8	5,50	8,70	B3-22x30	46,11 m2	B3-22x30	46,11	1470,00	B3-22x30	6,00	Pcs	130	€	€	€	€	€	€
Cobertura																	
C1	4	5	B3-22x25	5,00 Pcs	B3-22x25	5,00	47,57	B3-22x25	17,04	m	109	€	€	€	€	€	€
C2	6	5	B3-22x25	5,00 Pcs	B3-22x25	5,00	47,57	B3-22x25	17,04	m	109	€	€	€	€	€	€
C3	7	5	B3-22x25	6,00 Pcs	B3-22x25	6,00	47,57	B3-22x25	17,04	m	109	€	€	€	€	€	€
C4	6,5	5	B3-22x25	6,00 Pcs	B3-22x25	6,00	47,57	B3-22x25	17,04	m	109	€	€	€	€	€	€
R	0,37	4	B3-22x25	18,20 m	B3-22x25	18,20	6,00	B3-22x25	18,20	m	6,00	€	€	€	€	€	€
R	0,37	6	B3-22x25	21,60 m	B3-22x25	21,60	6,00	B3-22x25	21,60	m	6,00	€	€	€	€	€	€
R	0,37	7	B3-22x25	21,00 m	B3-22x25	21,00	6,00	B3-22x25	21,00	m	6,00	€	€	€	€	€	€
R	0,37	6,5	B3-22x25	20,00 m	B3-22x25	20,00	6,00	B3-22x25	20,00	m	6,00	€	€	€	€	€	€

Figure 3.13. Final details on quantities, price and transport details for rib and block slabs

3.2.1.2. Excel for Hollow-Core Slabs

In some situations, be it because of customer request, design limitation or SPRAL's decision, hollow-core slabs are the implemented solution. This type of slabs belongs to heavy duty precast and prestressed category, it is very expensive and suitable for slabs with great span and heavily loaded.

SPRAL has its own software to design hollow-core slabs. It presents the same concerns encountered on the software to design rib and block slabs in terms of outdated standards, lack of clarity regarding calculations. Additionally, the results do not follow an economic criterion and unless the designer restricts the height of the hollow-core panel, it will always show a solution using each type of panel (180, 265 and 400 millimetres of height) requiring the designer to manually check which one is cheaper.

There is one specific *Excel* file for hollow-core slabs divided in two *Excel* sheets, the first is related to the design and the second related to budgeting and transportation. The first *Excel* sheet of this document is designed to insert all the details from the project and any restriction like the height of the hollow-core slab panel, the height of the site-cast top slab or even the height of the finished slab (Figure 3.14). Designer can choose one or more restrictions or leave all blank. In case any restrictions are selected, the list of possible solutions only include the hollow-core panels that respect that restriction or restrictions. Otherwise it runs all the possible solutions.

It returns the design values and the best solution from an economic criterion from all the 21 different hollow-core slab panels produced at SPRAL combined with a site-cast top slab using a selected type of concrete and with variable height from 0 to 15 centimetres, for a total of 315 possible solutions. SPRAL advises to use at least a 4 centimetres site-cast slab. To select the best solution, this add-in takes in consideration the price of each type of panel per square meter and the price of the selected concrete.

Classe de betão C25/30		Preço		54		Aço A500			
INSERIR / PODE EDITAR									
Laje	Vão de Cálculo	A encher	Espessura do Painel	Camada de compressão	Espessura total da laje	Tipo de Utilização	Sobrecarga	Psi2	Revestimentos
Piso 0									
LP1	3,70	11,60	265			Habitacção	3	0,3	Tijoleira+areado
LP2	3,70	2,90		6		Habitacção	3	0,3	Tijoleira+assent./+isolamento
LP3	5,90	15,40			25	Habitacção	3	0,3	Tijoleira+assent./+isolamento
LP4	4,00	5,00				Habitacção	3	0,3	Tijoleira+assent./+isolamento
LP5	5,90	4,00				Habitacção	3	0,3	Tijoleira+assent./+isolamento
LP6	4,30	3,00				Habitacção	3	0,3	Tijoleira+assent./+isolamento
LP7	4,30	7,00				Habitacção	3	0,3	Tijoleira+assent./+isolamento
LP8	5,90	7,00				Habitacção	3	0,3	Tijoleira+assent./+isolamento
LP9	5,90	13,50				Habitacção	3	0,3	Tijoleira+assent./+isolamento
LP9	4,30	2,70				Habitacção	3	0,3	Tijoleira+assent./+isolamento
Piso 1									
LV1	3,10	5,70				Habitacção	3	0,3	Tijoleira+assent./+isolamento
LV2	3,00	2,30				Habitacção	3	0,3	Tijoleira+assent./+isolamento
LV3	2,80	3,00				Habitacção	3	0,3	Tijoleira+assent./+isolamento
LV4	2,80	3,00				Habitacção	3	0,3	Tijoleira+assent./+isolamento
LV5	2,30	4,30				Habitacção	3	0,3	Tijoleira+assent./+isolamento
LV6	5,00	1,40				Habitacção	3	0,3	Tijoleira+assent./+isolamento
LV7	8,00	1,40				Habitacção	3	0,3	Tijoleira+assent./+isolamento
LV8	14,00	3,00				Habitacção	3	0,3	Tijoleira+assent./+isolamento

Figure 3.14. Example of input values for hollow-core slabs

In terms of calculations, the initial goal, again, was to get to the same results as the current software. At this time, however, the program does not take in consideration limitations in deflection because no information was found about the counter-deflection used on the hollow-core slab panels and tests did not converge to acceptable results. Also, to have a future proof foundation, the few calculations already in place take in consideration the Eurocode as a standard.

This is a very simplistic approach to the design of hollow-core slabs and will require further development.

Design at ULS for bending

The first step is to compare the M_{sd} to M_{rd} . Self-weight of the slab panel, self-weight of the site-cast slab and weight of the finishing solutions selected are taken in consideration for permanent load value.

$$M_{sd} = \frac{(1,35 \times G + 1,5 \times Q) \times L^2}{8} \quad (13)$$

All the solutions that do not respect the condition M_{rd} equal or superior to M_{sd} is removed from the possible list of results.

Design at ULS for shearing

With the updated list of possible results, the software compares V_{ed} to V_{rd} .

$$V_{ed} = 0,55 \times (1,35 \times G + 1,5 \times Q) \times L \quad (14)$$

The value of V_{rd} must be equal or superior to the value of V_{ed} . The solutions where this condition is verified, move to the next step.

Design at SLS for bending

At this point the final verification is comparing the M_{freq} to M_{fctk} .

$$M_{freq} = \frac{(G + \psi_1 \times Q) \times L^2}{8} \quad (15)$$

From the list of possible solutions that verify these three criterions, the software uses a price list of every hollow-core slab panel and the price of the concrete for the site-

The options available to the user are the same, run the design process, verify if any product is modified by hand, find the best solution for transport and clear data (Figure 3.16). The design component it is the only thing not yet fully implemented and the second Excel sheet works independently if needed.



Figure 3.16. Ribbon options for hollow-core slabs

The following *Excel* sheet gathers the basic information about slabs, calculates the area of each and the corresponding number of hollow-core slab panels. The next section of this *Excel* sheet shows the information needed for the invoicing software, divided by storeys. The last section on the right is related to the transportation, displaying useful details about how many panels and from which slab should go on the same truck, the total number of trucks needed to complete this task and the prices. The 25 Ton trucks can only fit panels with a maximum length of 13 meters. Above that length, the software indicates the need of special transportation, grouping the panels in that situation. Again, it is possible to select which type of trucks to use and combine different storeys in one transport.

This output allows the user to easily import the data regarding the design to the invoicing software because the structure was designed to match and also provides excellent control over the transportation (Figure 3.17).

3.2.2. AutoCAD Plugin

AutoCAD or essentially any other computer-aided design software is a fundamental tool in all jobs related to civil engineering work. It is easy to learn but hard to master, and even then, the repetition of actions and commands are slow and susceptible to errors. During the early stages of the internship it was detected that the drafting process although essential for many different reasons, it was taking too long to complete.

The challenge was to develop a solution capable of improving what *AutoCAD* already does well, that is increase productivity and the quality of the drafting. In SPRAL's reality, a couple of repetitive tasks were identified: drafting of rib and block slabs (Figure 3.18), roof support systems (Figure 3.22), hollow-core slabs (Figure 3.25) and variable height beams.

On the first three problems, the drafting process uses the original project as a starting point and the intended result is a detailed blueprint of the slabs and roof construction also providing an accurate way of measuring dimensions and quantities of products that will be used.

The plugin *Spral-Lajes* for *Autodesk AutoCAD* was developed as an answer to this challenge. This plugin uses very simple input. It is available through commands or via the main menu of *AutoCAD*. It also exports the dimensions and quantities of products used. The list is saved in a format that is compatible with the invoicing software and the products are also identified with actual ID/references.

3.2.2.1. Drafting of rib and block slabs



Figure 3.18. Handmade draft (Left) compared to plugin result (Right) of rib and block slabs

Simply writing the command “lajesaligeiradas” or clicking the respective icon, will bring up the form with the options available (Figure 3.19). First is a dropdown menu with all the types and variations of rib and block slabs produced by SPRAL. The second and third spaces are related to the existence of balconies or other areas with lack of support that require the slab to work as a counter-weight. The most common way to deal with these situations in solutions with rib and block slabs, it is use an infill block lower in height, having a higher site-cast concrete slab that obviously weights more. On the next space, displaying 0 meters by default, it is asked to insert the distance to use in counter-weight, followed by the choice of what infill block to use.

The next option allows the user to select the orientation of the slab. Initially it was automatically selecting to have the slab work on the smallest span but later modified to respect the design decision of the engineer. The orientation of the beams can be set to parallel or perpendicular to the line user selects during the drafting.

The last option is a mirror functionality. It exists because the orientation line works as the X axis and the drafting is set to propagate from left to right and bottom to top.

Depending on the orientation line selected, it can happen to have the axis in reverse, mirror fixes that.

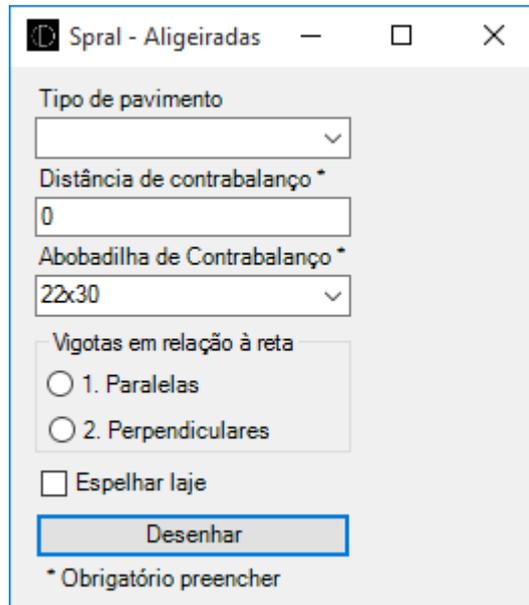


Figure 3.19. Options available in Rib and block Slabs

The user is asked to select the polyline representing the slab. Then select the two points that define the orientation. The plugin drafts all the rib and blocks of that slab and saves product quantities and dimensions.

A confirmation window pops up to confirm or dismiss the current draft. Confirming will permanently add the data to the bill of quantities, dismissing will give the opportunity to change the draft with no consequence to the bill of quantities.

Figure 3.20 is the end result of the drafting of an entire storey with rib and block slabs that takes less than five minutes to draft and fill the bill of quantities while it would take at least thirty minutes to complete it by hand, even by an experienced *AutoCAD* user.

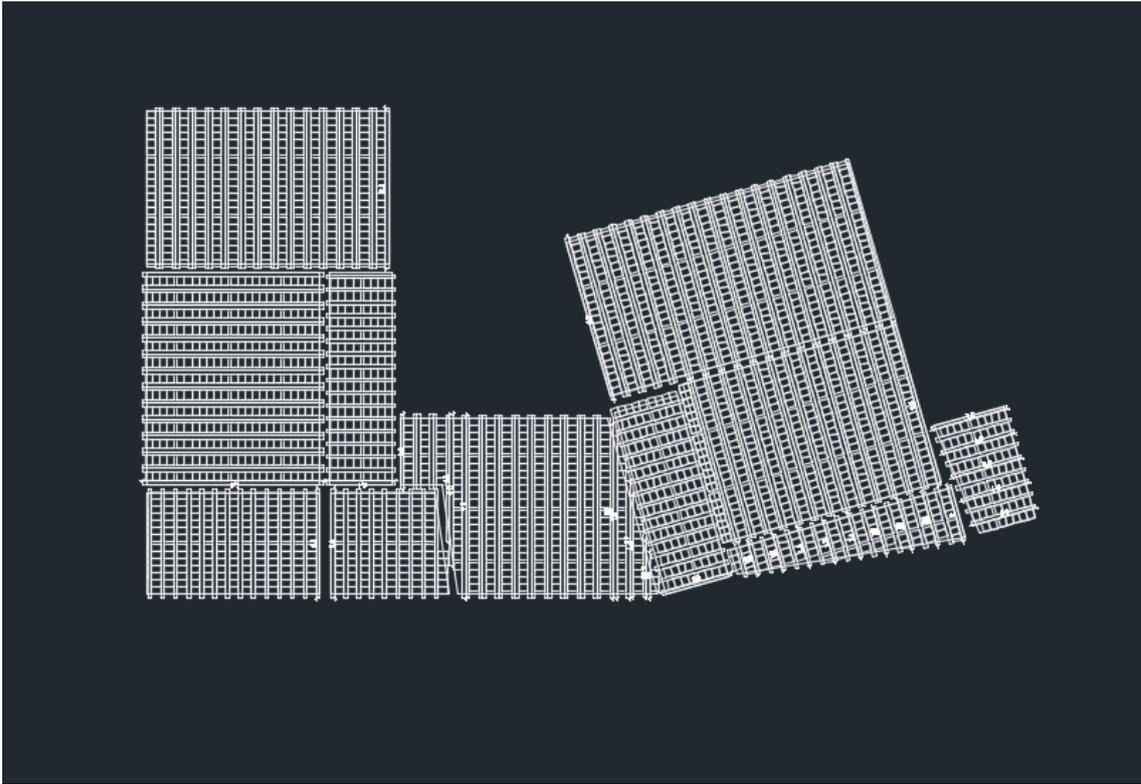


Figure 3.20. Example of a full storey drafting of rib and block slabs using the plugin

Figure 3.21 is the bill of quantities with all the information about the drafting, including product references and quantity. This is a comma separated file (CSV) that starts with the product reference and has the quantities after the comma. This type of file was chosen because the invoicing software is able to import it. It can gather information from one single slab, one storey or one building as long as the draft is done in the same *AutoCAD* file.

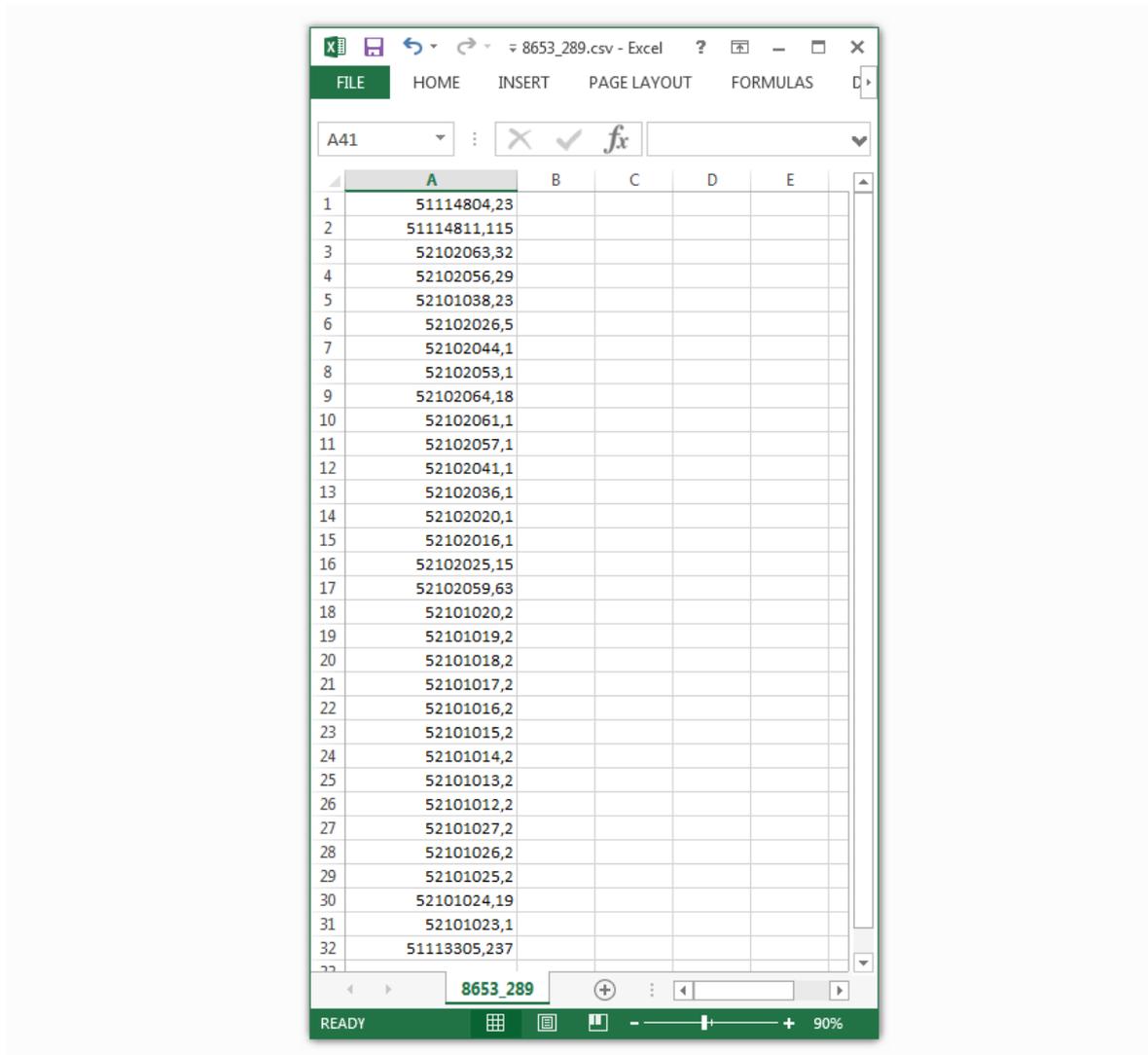


Figure 3.21. Example of the automatic bill of quantities saved by the plugin

The drafting follows SPRAL’s guidelines for this type of slab and the most relevant details are transverse beams 0,10 meters wide in slabs with span higher than 2 meters, support distance of each prestressed beam is at least 0,15 meters, prestressed beams are available in 0,10 meters increments starting from 1 meter, last infill blocks are added only if the distance between the previous block and the edge of the slab is greater than half the respective block length.

3.2.2.2. Drafting of roof support systems

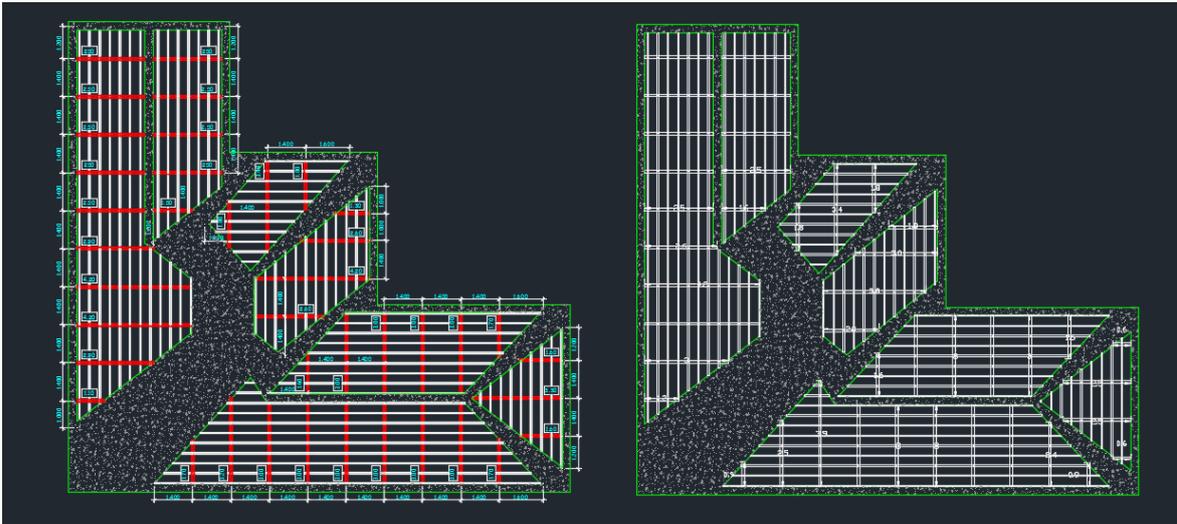


Figure 3.22. Handmade draft (Left) compared to plugin result (Right) of roof support systems

The options of roof support systems with concrete rafters and battens drafting are available through the command “coberturas” or selecting the icon available on the ribbon. Options available include the length of the tile to determine the distance between the concrete battens and also the orientation of the roof (Figure 3.23).

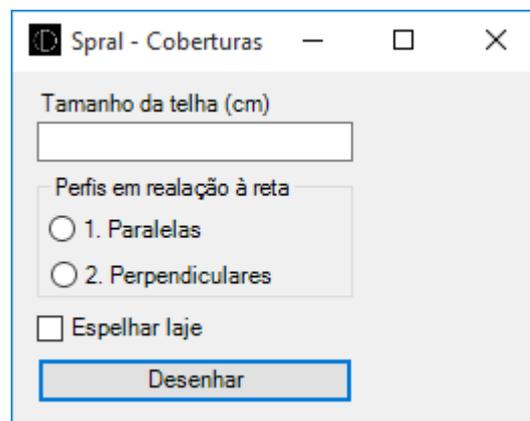


Figure 3.23. Options available in roof support systems

There are three different classes of concrete rafters, depending on the span of the roof. The plugin automatically selects the class according to the largest span of the roof and adjusts the distance between rafters accordingly. These rules are

established in SPRAL's documentation regarding roof support systems.

This is one example of a complete roof support system drafting using the software (Figure 3.24).

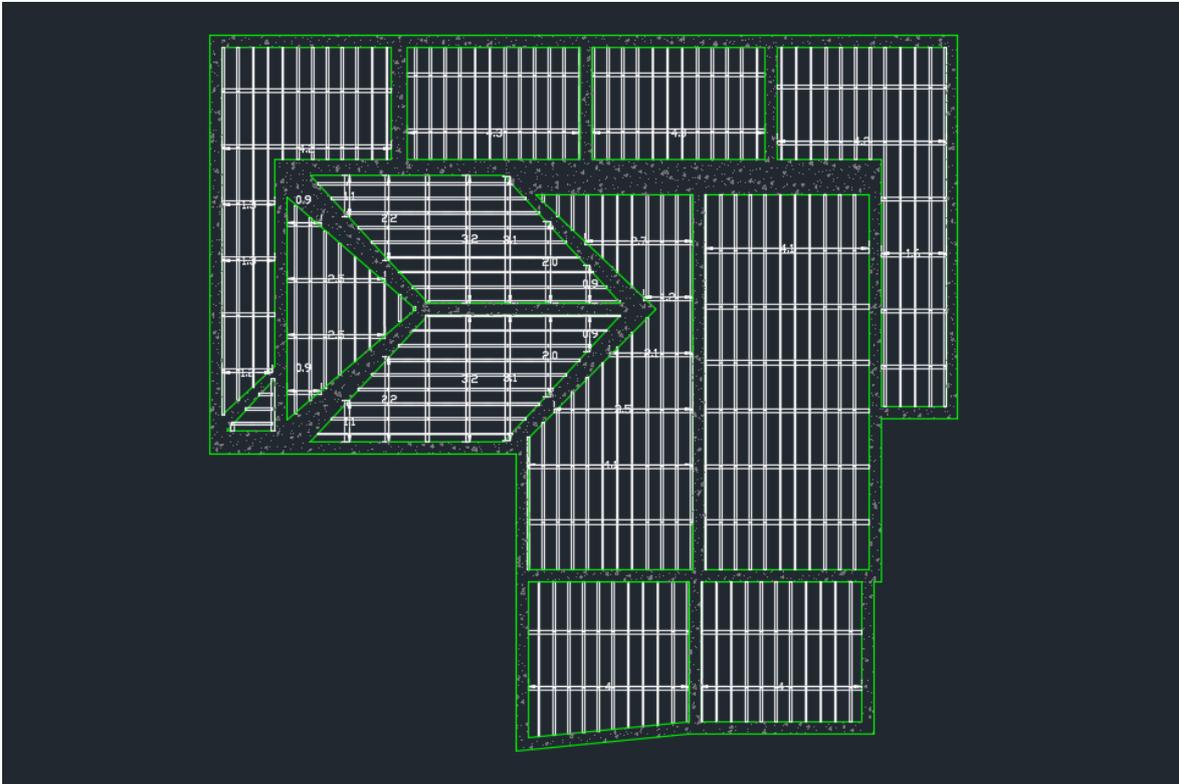


Figure 3.24. Example of a roof support system using the plugin

The number and dimension of rafters and battens are saved into a bill of quantities document that can easily be imported to the invoicing software.

Takes less than five minutes to draft and get the bill of quantities. Depending on the level of detail desired, it would take forty five minutes to one hour to complete by hand.

3.2.2.3. Drafting of Hollow-core slabs

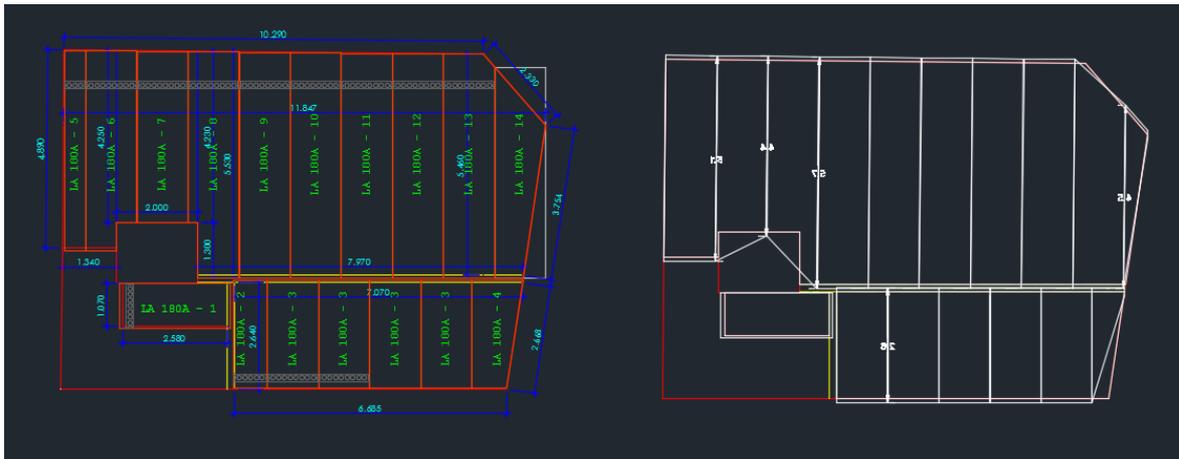


Figure 3.25. Handmade draft (Left) compared to plugin result (Right) of hollow-core slabs

Although hollow-core slabs are often used in complex projects and SPRAL has its own department with engineer and designing team to cover this heavy duty precast solutions, it is possible to improve the general productivity taking away some of the more simple and regular design requests.

The drafting options of hollow-core slabs on this plugin are available through the command “lajesalveolares” or by clicking on the ribbon icon.

It is given the user option to select the height of the hollow-core panel and if the panels should be drafted parallel or perpendicular to the line segment defined by the user (Figure 3.23).

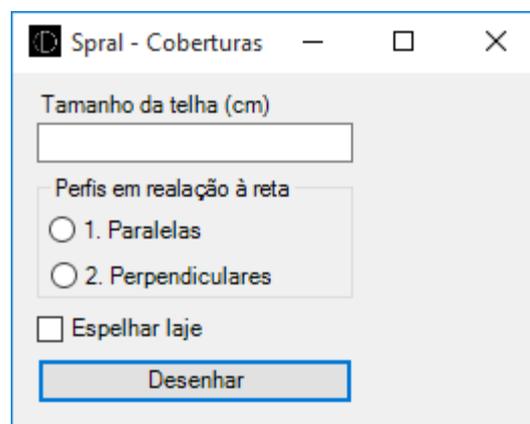


Figure 3.26. Options available hollow-core slabs

The support of each panel is at least 0,1 meters, the panels are spaced by 0,005 meters and the panel cuts were studied in order to never cross the any of the cores.

After the draft is confirmed, the quantities and dimensions are saved on a file but this time it needs to be modified before importing to the invoice software because the references used by SPRAL do not follow a specific pattern.

This plugin allows SPRAL to keep providing a very helpful construction blueprint to the customer while saving incredible amounts of time every day adding to it an accurate bill of quantities document.

It still requires continuous monitoring and development to ensure all the particular scenarios are covered. This plugin was developed using a limited number of real life examples from SPRAL's old and current projects.

Chapter 4

CONCLUSIONS

4. CONCLUSIONS

The main objective of this internship was the certification of fresh concrete production. In the end, SPRAL decided not to go through with the certification process. Regardless of the decision, product quality control and production process control were carried out during the internship period and the results obtained are in accordance with the normative requirements.

The NP EN 206-1:2007 it is not the most self-explanatory norm and lacks clarity on some concepts making it harder to work in compliance with it. It was also updated with two amendments. Other than that it takes in consideration the constraints of fresh concrete delivery using truck mixers which is crucial for concrete producers.

During the internship it was possible to develop some work on the internal laboratory of SPRAL, which is equipped with a variety of instruments to develop and test concrete products and related, giving the possibility to apply at scale some of the knowledge acquired during the early stages of the course.

To maintain the quality control of the four concrete production plants at SPRAL and also take care of some more laboratorial work for external services, it requires a full time laboratory technician.

The development of software tools, refreshing and applying knowledge of *VB.NET* and learning a new programming language, *C#*, identifying problems and creating advanced solutions to improve productivity in tasks related to civil engineering was a challenge completed with success.

Both software tools use established and widely used software, *Microsoft Excel* and *Autodesk AutoCAD*, and take them to new levels with an additional layer that was developed targeting specific needs of SPRAL. It does not have the flexibility of a human mind and understanding of the limitations of the production plants and for that reason it is possible to, sometimes, achieve different results by hand.

Not so much scientific research was done in a traditional sense but a much appreciated opportunity engage in real life problem solving around civil engineering, which was the original motivation to participate in the internship, with the added value of being in a company where people have lifetime experience in construction

and more specific in concrete products.

To take the most out of this internship opportunity, the chance to work on multiple activities, integrating different teams and taking care of projects on an individual level was more appealing than a narrow activity plan focused on only one task.

It was a good opportunity to see civil engineering from a different perspective. The course is more focused on design and academic exercises. The paradigm at SPRAL is often times to develop products and services that meet design requirements from other engineers.

As for future developments, aside from the continuous work on the software tools to add new features and finish the design capabilities for hollow-core slabs, it would be great to see SPRAL obtain the fresh concrete production certification. Other topic that was on the original self-purposed goals for the internship but was not addressed, is the study and implementation of measures to reduce environmental impact of concrete production plants, specially related to water usage.

REFERENCES

REFERENCES

Albahari, J.; Albahari, B. (2012). “C# 5.0 in a Nutshell”; California, USA; ISBN: 978-1-449-32010-2

Cachim, P. (2012). “Apontamentos Estruturas de betão”; Universidade de Aveiro, Portugal

Camposinhos, R. S.; Serra Neves, A. (2005). “Lajes Aligeiradas com Vigotas Pré-Tensionadas”; Faculdade de Engenharia da Universidade do Porto, Portugal; ISBN: 972-752-081-2

Instituto Português de Acreditação (2008). Circular a Clientes 01/2008; Caparica, Portugal; Available at <http://www.ipac.pt/docs/publicdocs/circulares/CC-01-2008.pdf>. Last visit on November 24th, 2015

Sika SikaComp 2.5; <http://prt.sika.com> Last visit on November 24th, 2015

Microsoft Excel; <http://products.office.com/pt-pt/excel> Last visit on November 24th, 2015

Autodesk AutoCAD; <http://autodesk.com/products/autocad> Last visit on November 24th, 2015

Microsoft Visual Studio; <http://visualstudio.com/> Last visit on November 24th, 2015

Spral Vigotas; <http://spral.pt/biblioteca.php?lang=1&id=267> Last visit on November 24th, 2015

NORMATIVE REFERENCES

NP EN ISO 9001:2000 – Implementação do Sistema de Gestão da Qualidade

NP EN 1992 – Eurocódigo 2: Projecto de estruturas de betão; Parte 1-1: Regras gerais e regras para edifícios;

NP ENV 13670-1:2007 – Execução de Estruturas Em Betão

NP EN 12620 – Agregados para betão

Decreto-Lei nº 301/2007 de 23 de Agosto

NP EN 206-1: 2007 Betão; Parte 1 – Especificações, desempenho, produção e conformidade; Emenda 1 2008; Emenda 2 2010

NP EN 12350 – Ensaio do betão fresco; Parte 1: Amostragem; Parte 2: Ensaio de abaixamento

NP EN 12390 – Ensaio de betão endurecido; Parte 1: Forma, e dimensões para ensaio de provetes e moldes; Parte 2: Execução e cura dos provetes para ensaios de resistência mecânicas; Parte 3: Resistência à compressão dos provetes de ensaio

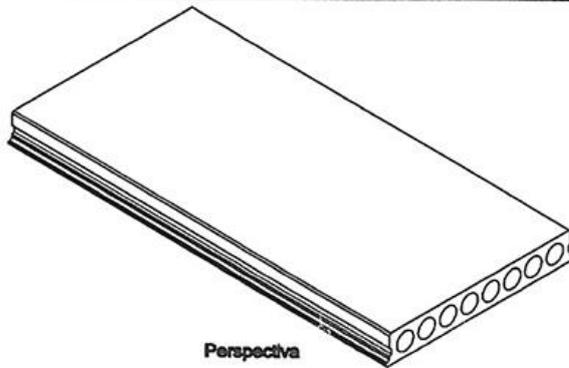
NP EN 933 Análise Granulométrica; Parte 1: Método da peneiração

ANNEX

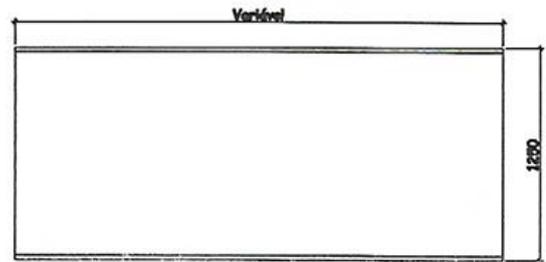
PRODUTO

Laje alveolada PE180

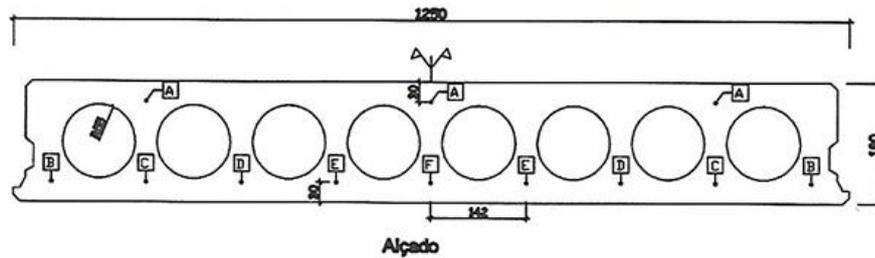
Desenho Técnico



Perspectiva



Planta



Alçado

Tipo	Armaduras					
	A	B	C	D	E	F
PE180_A	1 Ø 5 mm	1 Ø 9,3 mm	—	—	1 Ø 9,3 mm	—
PE180_B	1 Ø 5 mm	1 Ø 9,3 mm	—	1 Ø 9,3 mm	1 Ø 9,3 mm	—
PE180_C	1 Ø 5 mm	1 Ø 9,3 mm				
PE180_D	1 Ø 5 mm	1 Ø 9,3 mm	1 Ø 12,5 mm	1 Ø 9,3 mm	1 Ø 9,3 mm	1 Ø 12,5 mm
PE180_E	1 Ø 5 mm	1 Ø 9,3 mm	1 Ø 12,5 mm	1 Ø 9,3 mm	1 Ø 12,5 mm	1 Ø 12,5 mm
PE180_F	1 Ø 5 mm	1 Ø 9,3 mm	1 Ø 12,5 mm	1 Ø 12,5 mm	1 Ø 12,5 mm	1 Ø 12,5 mm
PE180_G	1 Ø 5 mm	1 Ø 12,5 mm	1 Ø 12,5 mm	1 Ø 12,5 mm	1 Ø 12,5 mm	1 Ø 12,5 mm

CARACTERÍSTICAS DO PRODUTO

Dimensão nominal	(comprimento x largura x altura)	V artével x 1250 x 180
Massa	kg/m ²	290
Classe de resistência à compressão do betão	N/mm ²	C45/55
Tensão de rotura à tracção do fio	N/mm ²	1770
Tensão de cedência à tracção do fio	N/mm ²	1550
Tensão de rotura à tracção do cordão	N/mm ²	1860
Tensão de cedência à tracção do cordão	N/mm ²	1600
Resistência mecânica / Resistência ao fogo / isolamento ao ruído aéreo e índice de isolamento ao ruído por percussão / Especificações construtivas / Durabilidade	Especificações de projecto	(pedido do cliente)

ihavo
EN 1168

 Escritório 1 e Fábrica 1
 Rua Lagoa do Junco, 119
 Moitinhos
 3630-285 Ihavo

 Geral
 Tel 234 329 480
 Fax 234 329 481

 Comercial
 Tel 234 329 485
 Fax 234 329 486

Annex B

Cliente
 Morada
 Proprietário
 Local da Obra
 Observações:

SPRAL, L.DA
 QUINTAS-ILHAVO
 Date / / 2015
ORÇAMENTO
 N.º

Lote	Viz. de Célula	L. cnetor	Tipo de tij	Área parcel	No de parcel	TOTAL	MATERIAL NA FÁBRICA		MATERIAL NA OBRA	
							Unid. de	Custo	Unid. de	Custo
Piso 1										
L1	6,10	3,80	283-33x25-30	x		23,18 m ²				
11	4,40	4,60	B3-40x25-30	o		20,24 m ²				
L2	7,00	8,80	284-33x25-30	x		61,60 m ²				
L3	4,50	8,80	B3-40x25-30	o		39,60 m ²				
Σ L4	7,00	8,00	284-33x25-30	x		7,00 m ²	91,78 m ²	28-33x25	2,57	
Σ L5	3,10	9,20	B3-40x25-30	o		29,52 m ²				
Σ L1.1	3,80	8,50	"			32,30 m ²	88,36 m ²	B-40x25	0,49	
Piso 2										
L1	7,10	8,00	284-33x25-30	x		7,00 m ²				
L2	6,90	3,10	"	x		21,39 m ²				
L3	7,10	7,00	"	x		49,70 m ²				
L4	7,10	6,90	"	x		48,99 m ²				
L5	6,70	7,10	"	x		47,57 m ²	174,25 m ²	28-33x25	1,93	
L6	2,40	7,10	B2-40x25-30	o			17,04 m ²	B-40x25	0,10	

25 ton.
 (1) €

25 ton.
 (1) € +
 15 ton.
 (1) €

NOTA:
 ERRO NA ÁREA TOTAL B3-40x25
 FALTOU CONSIDERAR L.1.
 DA 2 CAMIÕES (25 + 15)
 02/08/15

Annex C

Ver. =

Cliente: _____
 Modelo: _____
 Proprietário: _____
 Local de Obra: _____
 Observações: _____

SFRAL, L.D.A.
 QUINTAS - ILHAÇO
 Date: 1/ 12/2015
ORÇAMENTO
 N.º _____

Laje	Vão de Cálculo	A. encher	Tipo de laje	Área parcial	No de perfis	TOTAL	MATERIAL NA FÁBRICA		MATERIAL NA OBRA	
							Unidade	Custo	Unidade	Custo
<u>PISO</u>										
LP1	3,70	11,60	2,335	42,92 M ²		46,05 M ²	10 PEGAS		PE 180 B	
LP2	3,70	11,60	2,335	42,92 M ²		46,05 M ²	10 PEGAS			
LP3	5,90	2,90	7,375	17,11 M ²		22,13 M ²	3 PEGAS			
LP4	5,90	15,40	7,375	90,86 M ²		95,88 M ²	13 PEGAS			
"	4,30	3,00	5,725	12,90 M ²		16,13 M ²	3 PEGAS			
LP5	5,90	4,00	7,375	23,60 M ²		22,13 M ²	3 PEGAS			
"	4,50	3,00	5,725	13,50 M ²		16,88 M ²	3 PEGAS			
LP6	4,50	7,00	5,725	31,50 M ²		33,75 M ²	6 PEGAS			
LP7	5,90	7,00	7,375	41,30 M ²		44,05 M ²	6 PEGAS			
LP8	5,90	13,50	7,375	79,65 M ²		81,13 M ²	11 PEGAS			
"	4,30	2,70	5,325	11,61 M ²		10,75 M ²	2 PEGAS			
LV1	3,10	5,70	3,375	17,67 M ²		19,38 M ²	5 PEGAS			
LV2	3,00	2,30	3,375	6,90 M ²		7,50 M ²	2 PEGAS			
LV3	2,80	3,00	3,375	8,40 M ²		10,50 M ²	3 PEGAS			
LV4	2,80	3,00	3,375	8,40 M ²		10,50 M ²	3 PEGAS			
LV5	2,30	4,30	3,375	9,89 M ²		11,50 M ²	4 PEGAS			
"	5,00	1,40	5,725	7,00 M ²		6,25 M ²	1 PEÇA			
<u>TETO (COBERTURA)</u>										
LT1	5,90	7,00	7,375	41,30 M ²		44,05 M ²	6 PEGAS		PE 180 B	
LT2	5,90	7,00	7,375	41,30 M ²		44,05 M ²	6 PEGAS			
LT3	5,90	15,40	7,375	90,86 M ²		95,88 M ²	13 PEGAS			
"	4,30	3,00	5,725	12,90 M ²		16,13 M ²	3 PEGAS			
LT4	7,30	8,70	9,125	63,51 M ²		63,88 M ²	7 PEGAS			
"	4,30	1,50	5,725	6,45 M ²		5,38 M ²	1 PEÇA			
LTS	5,90	20,70	7,375	122,13 M ²		125,38 M ²	17 PEGAS			
"	4,30	2,60	5,725	11,18 M ²		10,75 M ²	2 PEGAS			
LV6	3,00	2,30	3,375	6,90 M ²		7,50 M ²	2 PEGAS			
LV7	2,80	3,00	3,375	8,40 M ²		10,50 M ²	3 PEGAS			
LV8	2,80	3,00	3,375	8,40 M ²		10,50 M ²	3 PEGAS			
LV9	2,30	4,30	3,375	9,89 M ²		11,50 M ²	4 PEGAS			

TRANSP. 25 Ton.
 501,96 / 85
 (6)

TRANSP. 25 Ton.
 492,95 / 85
 (6)