ISCTE-IUL

I. HOTEL PORTUÁRIO EM SINES

II. Performance of Cross-Laminated Timber Walls

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Escola de Tecnologias e Arquitetura
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VERTENTE PROJECTUAL
trabalho prático submetido como requisito parcial para a obtenção de grau de Mestre em Arquitetura

VERTENTE TEÓRICA
trabalho teórico submetido como requisito parcial para a obtenção de grau de Mestre em Arquitetura

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Introdução

No âmbito do exercício proposto para Projeto Final de Arquitetura no Mestrado Integrado em Arquitetura (MIA) do ISCTE-IUL, foi desenvolvido, no ano lectivo 2015/2016, o presente trabalho, para o «Concurso Universidades» integrado na programação da Trienal de Arquitetura de Lisboa 2016, com o tema «Sines – Industria e Estrutura Portuária». Pretendeu-se com este trabalho explorar a estratégia de desenvolvimento de Portugal, refletindo sobre o papel de Sines na Europa e no mundo. O elevado potencial de Sines no crescimento económico do País é indiscutível, mas existem múltiplas possibilidades capazes de satisfazer este objetivo. Por essa razão foi necessário explorar as múltiplas articulações possíveis desde a escala do território às do projeto de arquitetura dos edifícios e vice-versa. O resultado desta investigação é apresentado demonstrando as várias possibilidades consideradas, no sentido de encontrar uma estratégia de intervenção em que a definição do Espaço Público cumpre a sua função estruturante do território.

I. VERTENTE PRÁTICA

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Fig.01 VISTA AÉREA DA CIDADE DE SINES

1. Localização da cidade de Sines

“A cidade de Sines, sede de freguesia e do concelho de Sines, pertence ao Distrito de Setúbal e dista aproximadamente 160 Km de Lisboa; 80 Km de Setúbal e 140 Km de Évora. Localizada a Sul do país na região natural do Sado e Ribatejo, a cidade se Sines está enquadrada pela Ribeira de Morgavel a sul, pelo maciço da Serra do Cercal a Este e pela Lagoa de Santo André a Norte. O desenvolvimento dos primeiros aglomerados urbanos, até 1970, é sobretudo de índole rústica/rural, mantendo uma estreita relação com o Oceano Atlântico.” [1]

Fig.02 Mapa de Portugal

Sines 1960

Sines 1988

Sines 2005

Fig.03 Evolução do território de Sines

2. Evolução histórica da cidade

Portugal é um território litoral no qual o mar assume um papel importante em vários aspetos e desde os tempos mais remotos motivou o aparecimento de assentamento urbanos, pesqueiros e portuários, arrogando-se como fonte de alimento, potenciador de trocas comerciais, movimento de pessoas e bens. (...) Na cidade de Sines os primeiros povos remontam ao Palolítico Inferior, havendo também vestígios pré-Celtas e Celtas. No entanto a presença Romana foi a que deixou marcas mais evidentes no território. (...) O povo romano foi, deste modo, o primeiro povo a introduzir simultaneamente as componentes industrial e portuária em Sines, no qual a actividade piscatória desempenhava o papel principal. [1] Verifica-se consultando a evolução urbana de Sines (fig.03) que o assentamento urbano se desenvolve em torno da baía crescendo lentamente em direcção ao interior. É no final da década de 1970 que se verifica o desenvolvimento urbano mais acentuado, após a implementação do Plano Geral da Área de Sines.

Fig.04 Area de Desenvolvimento de Sines 1970

O Plano Geral da Área de Sines foi elaborado na década de 60, durante o período do Estado Novo, com o intuito de desenvolver a zona de modo semelhante ao que aconteceu com Setúbal em 1930. “A partir dessa data toda a realidade da vila é alterada, milhares de trabalhadores acorrem à vila, numa primeira fase apenas trabalhadores em estadias temporárias, que edificavam as infraestruturas do porto e da refinaria e mais tarde em definitivo trabalhadores oriundos da região de Setúbal, de Lisboa e das ex-colónias que se fixam na região com as suas famílias.” [2]

O plano provocou um enorme crescimento na cidade e estima-se que durante a sua construção, entre a década de 70 e de 80, a população de Sines tenha aumentado mais de 90%. Por essa razão é criada a Vila Nova de Santo André a 10 km de Sines, para alojar os trabalhadores vindos de outras partes do país. “Perante o panorama delineado, o governo criou, por Decreto-Lei nº 270/71, promulgado em 19 de Junho de 1971, uma estrutura específica para a gestão do projeto de implantação de um polo industrial - O Gabinete da Área de Sines (GAS) - estruturado em torno do porto de Sines, No entanto, este gabinete é extinto pelo “ Governo Constitucional por resolução do Conselho de Ministros de 06.02.86 (D.R. nº32 - II Série) com extinção efetiva em 1988, após os tumultuosos anos de 1974 aquando da reforma administrativa que previa a redução da dimensão do Estado e de especialização de competências específicas devidamente hierarquizadas a nível central, regional e autárquico.” [3]

A cidade de Sines conforme o projeto de 1972 comportava três vectores integrados: centro urbano, porto e indústria (fig.04) que contribuíram de forma significativa para a sua fisionomia atual.

Com a sua dimensão de cidade logística e empresarial, Sines apresenta atualmente “um conjunto de oportunidade de desenvolvimento potenciadas por projetos de grande envergadura, em desenvolvimento, concretizados ou em vias de concretização, mobilizadores de iniciativa pública e privada, com efeitos benéficos na estruturação do sistema urbano regional e, em especial, na aceleração do processo de internacionalização do território.“ [3]

Fig.05 Vista aérea da Pedreira de Sines

3. Análise do Território

Sines estabelece-se como um território de particular relevância estratégica no desenvolvimento da costa alentejana, como força dinâmica de progressão territorial. Este papel é reforçado sobretudo pela posição central que ocupa entre a metrópole e a zona Sul do país. Cabe a Sines, estabelecer condições para atingir resultados que permitam optimizar os efeitos de reciprocidade com estas duas cidades, a níveis sobretudo económicos mas também sociais, turísticos e de empreendorismo.

No contexto regional da zona ribatejana onde predominam as ocupações dispersas, predominantemente rurais, especialmente no interior do país, Sines, Santiago do Cacém e Santo André constituem o triângulo de potenciais núcleos urbanos com maior capacidade de desenvolvimento geográfico exercendo fenómenos de redistribuição de dinâmicas territoriais competitivas e sustentáveis.

Para o exercício proposto em Projeto Final de Arquitetura o reconhecimento do território foi feito através de sucessivas visitas ao local, organizadas pela Trienal de Lisboa e pelos docentes do ISCTE-IUL. O objetivo da primeira viagem foi o de estabelecer uma imagem mais ou menos clara dos principais problemas que atormentam a cidade bem como tomar consciência das várias datas do edificado. Começando pela pedreira (fig.06), a sua magnitude e rara beleza é difícil de ignorar, com camadas e camadas de pedra retiradas para construir a zona costeira do Porto. Esta ferida na cidade ilustra bem o diálogo que se tem estabelecido entre os industriais e as entidades locais. Um diálogo amargo entre entidade locais que sempre quiseram que tudo se mantivesse como tinha sido e entre industrias que sempre quiseram que o país avança-se. A aposta na modernização do Porto de Sines difícil de acompanhar pela cidade e resultou numa população ressentida que vê com sacrifício a sua patriótica cidade ser dominada pelo ritmo acelerado da evolução da indústria na cidade de Sines.

Fig.06 Fotografia da Pedreira

No centro histórico podem ver-se vários edifícios abandonados e devolutos mas também uma cidade que se quer modernizar no plano cultural e artístico. Com diversos museus e uma programação sazonal particularmente ativa. Esta estratégia parece ter funcionado em certa medida pois podemos encontrar alguns turistas durante a época alta. No entanto, a cidade está de facto bastante datada por falta de apostas significativas no seu desenvolvimento. Quando o Porto inicia a sua proliferação na cidade piscatória de Sines, a cidade de Santo André é criada a 10 km com o intuito de absorver a maior parte mão de obra necessária para o Porto. Este investimento fazia todo o sentido no âmbito do plano elaborado, alocando os trabalhadores a norte da poluição provocada pela indústria, no entanto a cidade não foi construída a tempo o que exerceu uma grande pressão sobre a vila de Sines que se viu obrigada a alocar este crescimento num antigo paquete ou em habitações precárias, levando mais tarda á construção do bairro 1º de Maio pelo qual passámos na fase final da visita. (fig.07)

Fig.07 Bairro 1º de Maio

Após este primeiro contacto com o território, a turma reuniu esforços na tentativa de o compreender em sua plenitude, procurando ativamente recursos que permitissem determinar: a evolução urbana da cidade, o estado de conservação dos edifícios, equipamentos, distribuição e tipo de vegetação, entre outros. Para este propósito foram criados oito grupos de trabalho cada um com a sua responsabilidade. (fig.04) Os dados recolhidos através do Censos (fig.05 e fig.06) permitiram mais tarde elaborar indicadores demográficos e formar uma imagem clara das condições económico-sociais que caraterizam esta cidade.

G1	Levantamento de edifícios em ruínas / edifícios de habitação
G2	Limpar planta / Atualizar edificado / Estrutura viária
G3	Mapa de zonamento (bairros/pontos de referência / edifícios religiosos)
G4	Maquete 1:5000
G5	Evolução histórica / Cartografia – 1743 a 2000
G6	Análise da linha costeira de Sines
G7	Estrutura Social
G8	Montagem do Caderno

Fig.08 Grupos de Trabalho - Professor Botelho

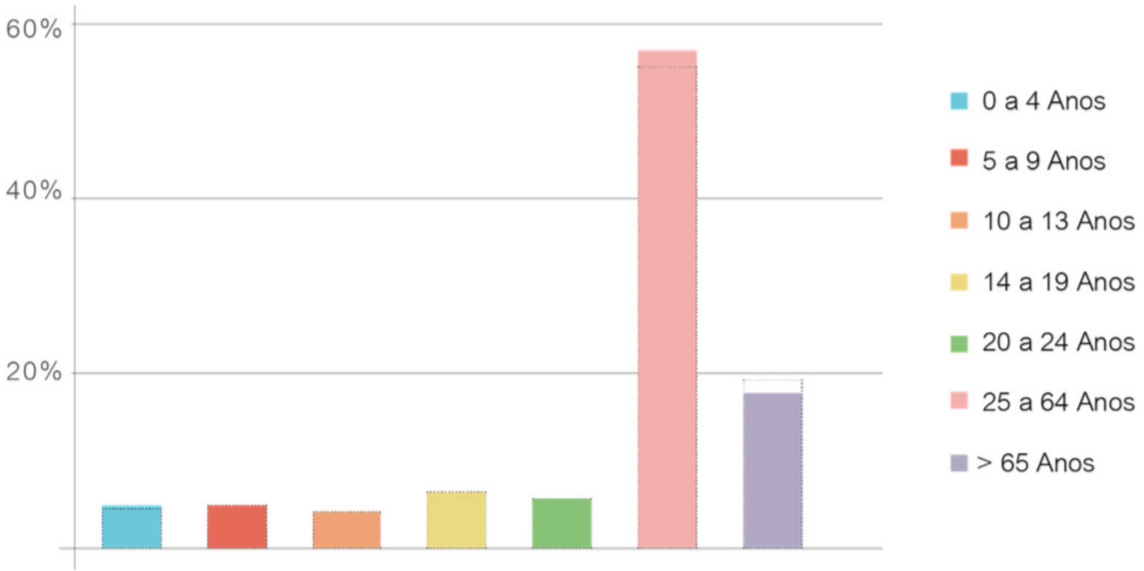


Fig.09 Distribuição Etária do Conselho de Sines - Em relação ao país

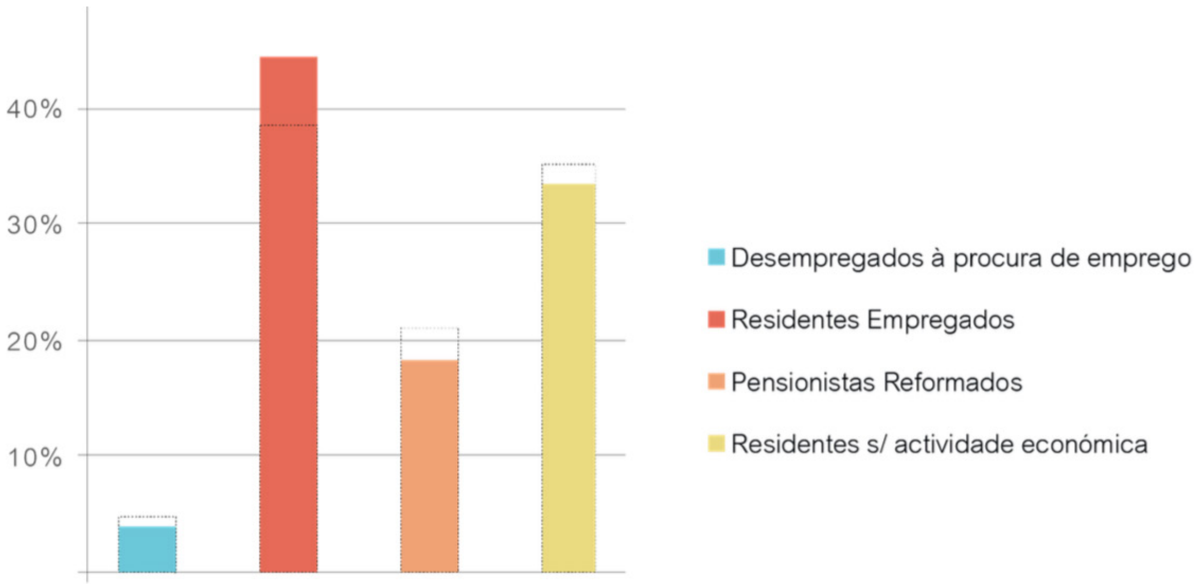


Fig.10 Situação económica do Conselho de Sines - Em relação ao país

FIG.11 VISTA AÉREA DA CIDADE DE SINES

1. PROPOSTA DE GRUPO

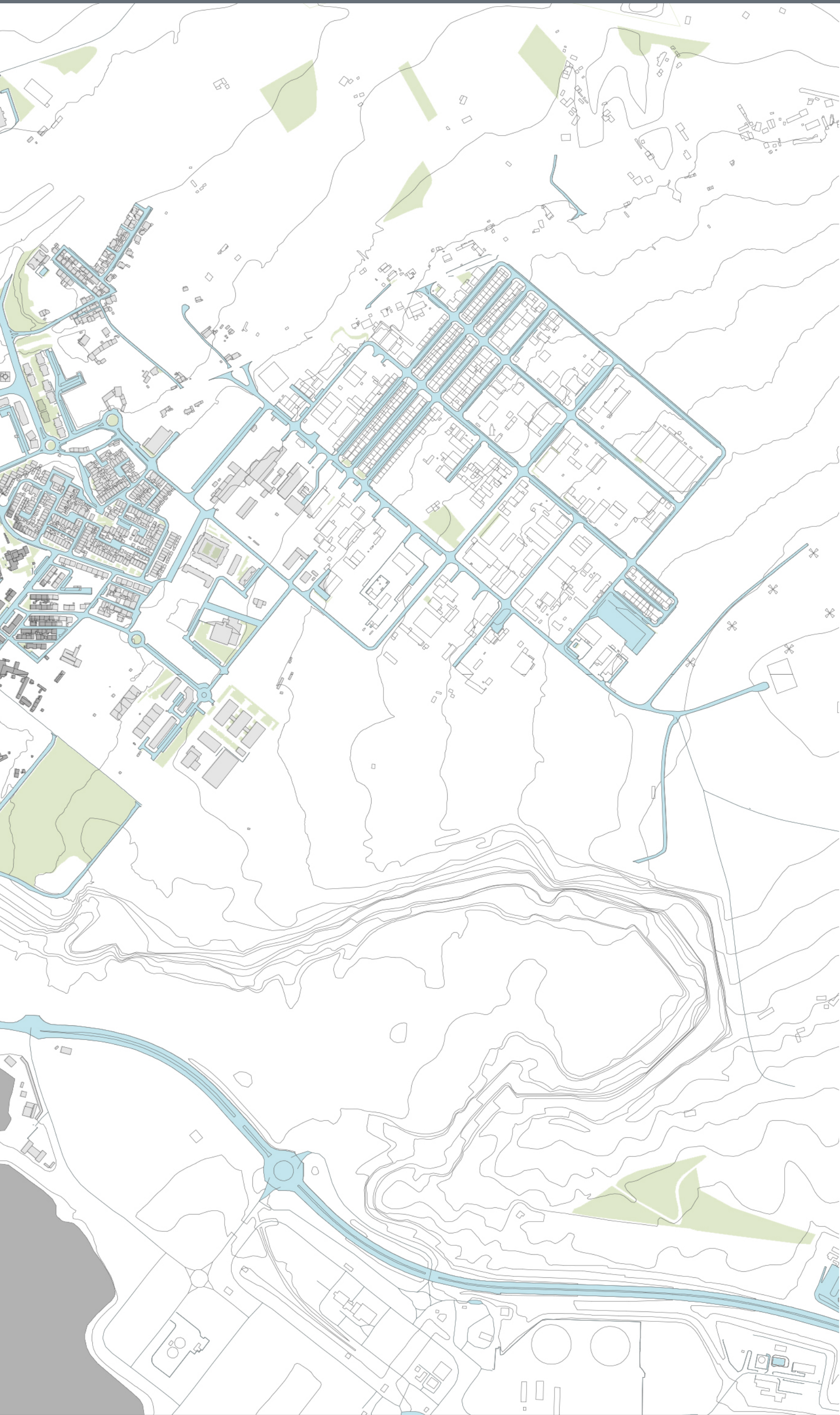


Fig.12 Evolução Urbana de Sines
Os levantamentos feitos em turma demonstraram que a cidade teve um desenvolvimento em torno do porto de pesca e da praia. A cidade conserva o ambiente de antigamente mas a linha costeira tem sido dramaticamente alterada. Nesta carta percorre-se o Roteiro do Centro Histórico conforme sugerido pela Câmara Municipal de Sines.

Roteiro do Centro Histórico

1. Antiga Calheta
2. Igreja de Nossa Senhora das Salas
3. “Casa de Vasco da Gama”
4. Castelo / Museu de Sines
5. Centro de Artes de Sines
6. Porto de Pesca
7. Praia de Sines
8. Porto Recreativo

1973 - 2016
1953 - 1971
1943 - 1945
1699 - 1743

1.Antiga Calheta

Apesar de ser o melhor porto do Alentejo de antigamente, nem sempre era fácil aportar em Sines, pelo que desde o século XVI se conhecem projetos de melhoria e ampliação da Calheta, saídos da mão dos melhores engenheiros militares. O conjunto de armazéns, muros de suporte e rampas conserva-se imponente mas parcialmente cortado pela nova avenida. [4]

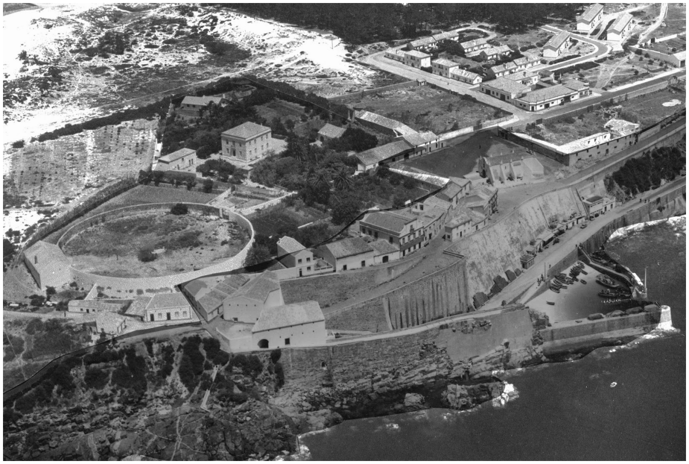


Fig.13 Antiga Calheta

2.Igreja de Nossa Senhora das Salvas

O edifício de inícios do século XIV está conservado na íntegra, sendo o seu interior enriquecido com retábulos de talha setecentistas e um notável ciclo de azulejos. Fundada pela princesa grega D.Vataça Lascaris, foi reconstruída por Vasco da Gama. Hoje é possível visitar o tesouro, onde se expõe joias oferecidas à Senhora ao longo dos séculos. [4]

Fig.14 Igreja de Nossa Senhora das Salvas.

Fig.15 Casa de Vasco da Gama,

3.Casa de Vasco da Gama

Demolida em finais do século XIX esta casa é o local onde Vasco da Gama começou a erguer a sua residência após o regresso da Índia. Apesar da placa colocada na fachada em 1896 assinalar a casa como o local do nascimento do navegador. [4]

Fig.16 Castelo de Sines.

4.Castelo / Museu de SInes

D. Pedro I elevou Sines a vila no dia 24 de novembro de 1362 na contrapartida de que os seus habitantes finalizassem a reconstrução das muralhas do Castelo que caíram em consequência do terramoto de 1755. No rés-do chão são visíveis muitos elementos arquitectónicos do tempo dos Gama, e o 1º andar reflete o gosto da segunda metade do século XVIII. [4]

5.Centro de Artes de Sines

Construído em 2005 no âmbito do Programa de Regeneração Urbana de Sines este espaço polivalente foi desenhado pelos arquitetos Aires Mateus com o intuito de acelerar a forte aposta de Sines na cultura e nas Artes. Este armazém é um edifício sublime do ponto de vista arquitectónico onde se abrigam diversas exposições e concertos. [4]

Fig.17 Centro de Artes de Sines

6.Porto de Pesca

A pesca sempre fez parte do quotidiano sineense, e como tal, o porto de pesca sempre foi uma parte integrante da cidade. Atualmente oferece um cais de aprestos e um cais de descarga de peixe, rampa de varadouro e diversas instalações terrestres de apoio. É formado por uma bacia interior, abrigada por um quebra-mar e oferece boas condições de proteção para acostagem. [6]

Fig.18 Porto de Pesca

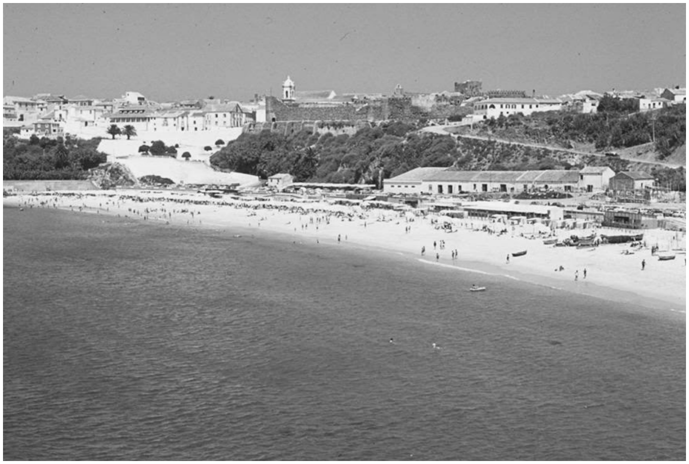


Fig.19 Praia de Sines, fotografia de Arquivo

7.Praia Vasco da Gama

Durante o século XIX frequentava-se por razões de saúde e tinha um Estabelecimento de Banhos Quente, mas foi progressivamente tornando-se num lugar de lazer e na praia favorita dos alentejanos. A Avenida Vasco da Gama que contorna a praia, foi requalificada no âmbito do Programa de Regeneração Urbana de Sines. [4]

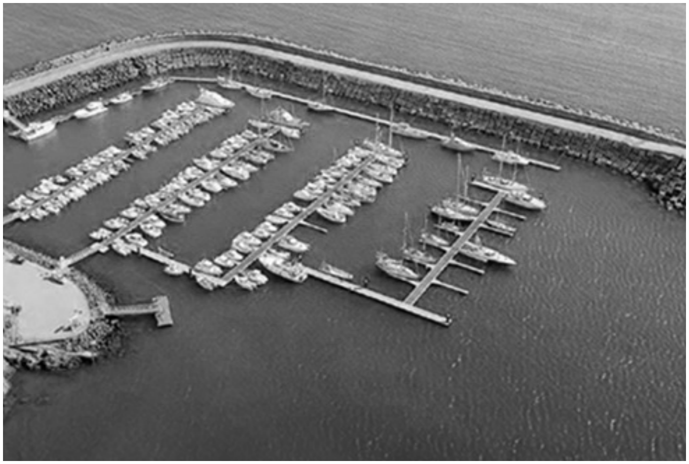


Fig.20 Porto Recreativo, fotografia de Arquivo

8.Porto Recreativo

O Porto Recreativo, construído na história recente de Sines, é o único porto de recreio da costa marítima entre Setúbal e Algarve, numa zona onde a navegação de recreio é intensa todo o ano. O porto inclui um cais de alagem, rampa de varadouro, grua móvel, retenção marginal, terraplenos e passadiços flutuantes para acostagem de embarcações. [6]

Nos anos recentes a cidade atualizou-se e desenvolveu um plano de expansão (fig.19) que apesar de apostar fortemente na habitação também tem espaço reservado para equipamentos administrativos/cívicos, equipamentos culturais e de domínio desportivo. Foi ainda prevista uma área para 2 hotéis com um grande parque urbano. A principal inovação na rede viária, que se reflete na estrutura urbana é a criação de uma alameda urbana que percorre toda a área do plano da zona sul até à marginal. Em 2011 o arquiteto José Carlos Varela Lima construiu algumas vivendas na primeiro zona de expansão do plano geral. (fig,18) Até ao momento de escrita deste trabalho, é a única porção completa do plano. [5]

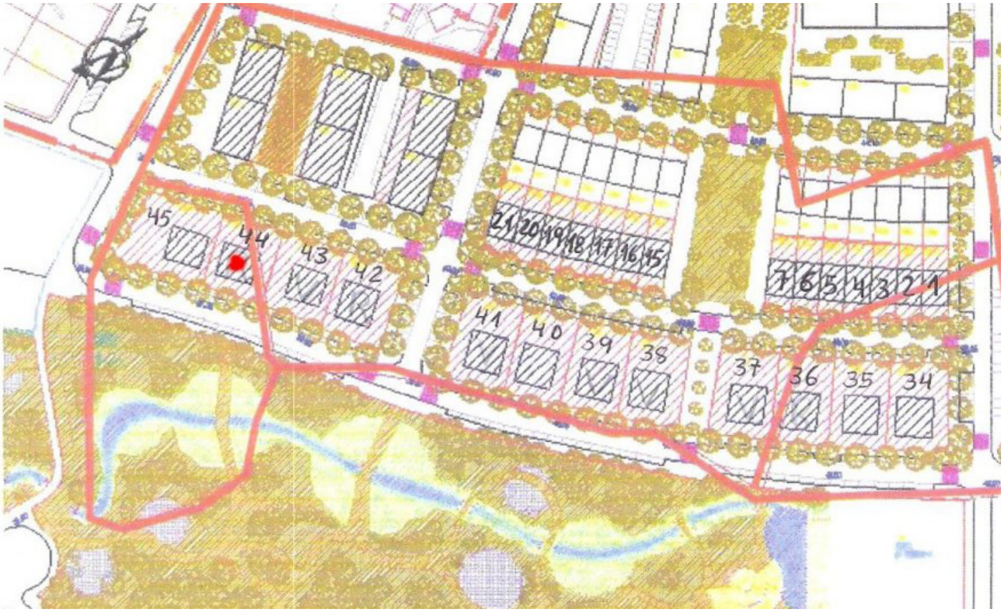


Fig.21 Urbanização do Convento

Fig.22 Plano Geral de Expansão

1. PROPOSTA DE GRUPO

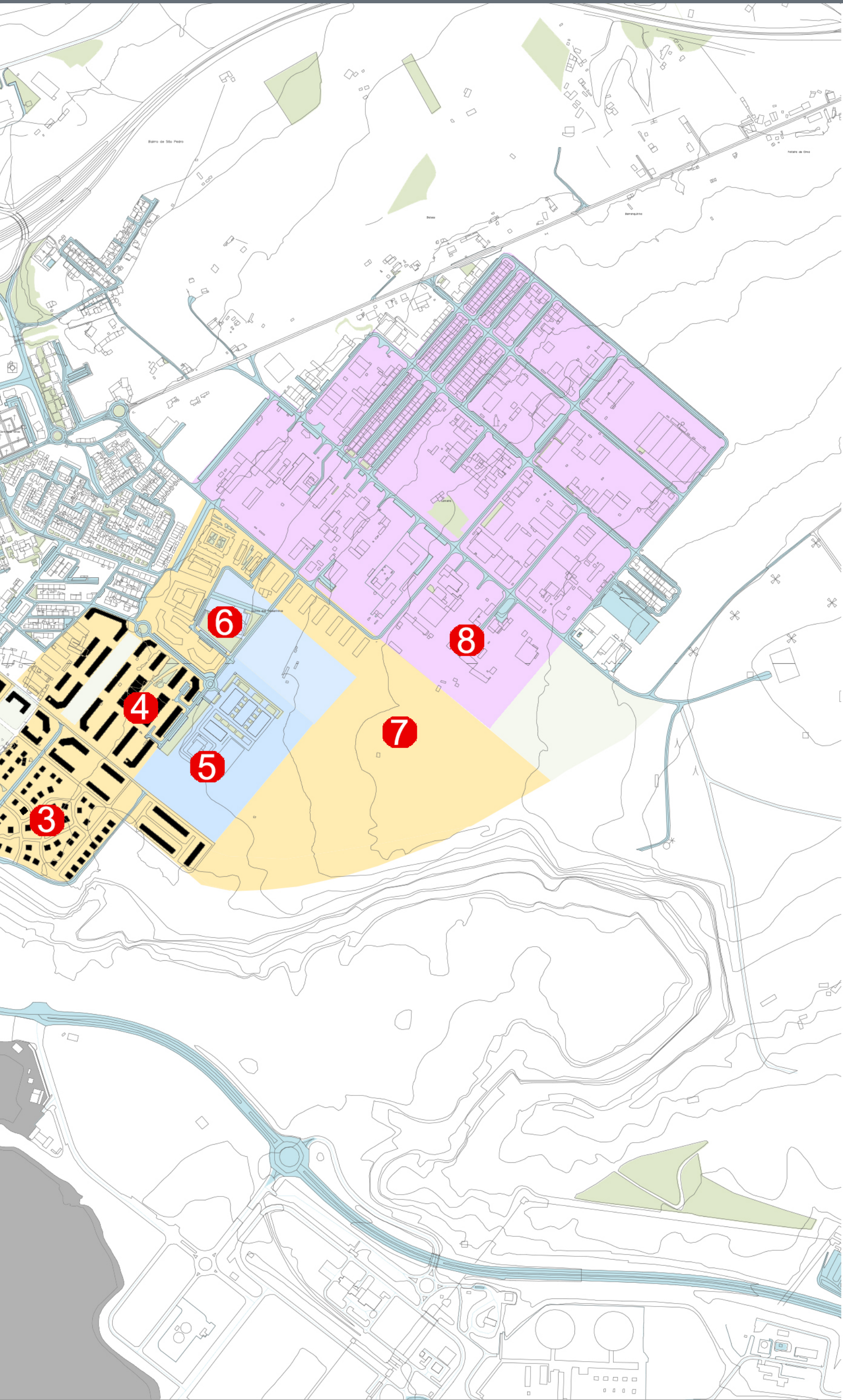


Fig.23 Expansão da Cidade de Sines

O Plano de Pormenor da zona de Expansão Sul-Nascente da Cidade entrou em vigor no dia 16 de Janeiro de 2008 com a intenção de expandir Sines. O plano abrange uma das áreas consideradas prioritárias para o crescimento da cidade. Tem planeada capacidade para alojar 3800 pessoas, sendo 80% da área designada para uso habitacional.

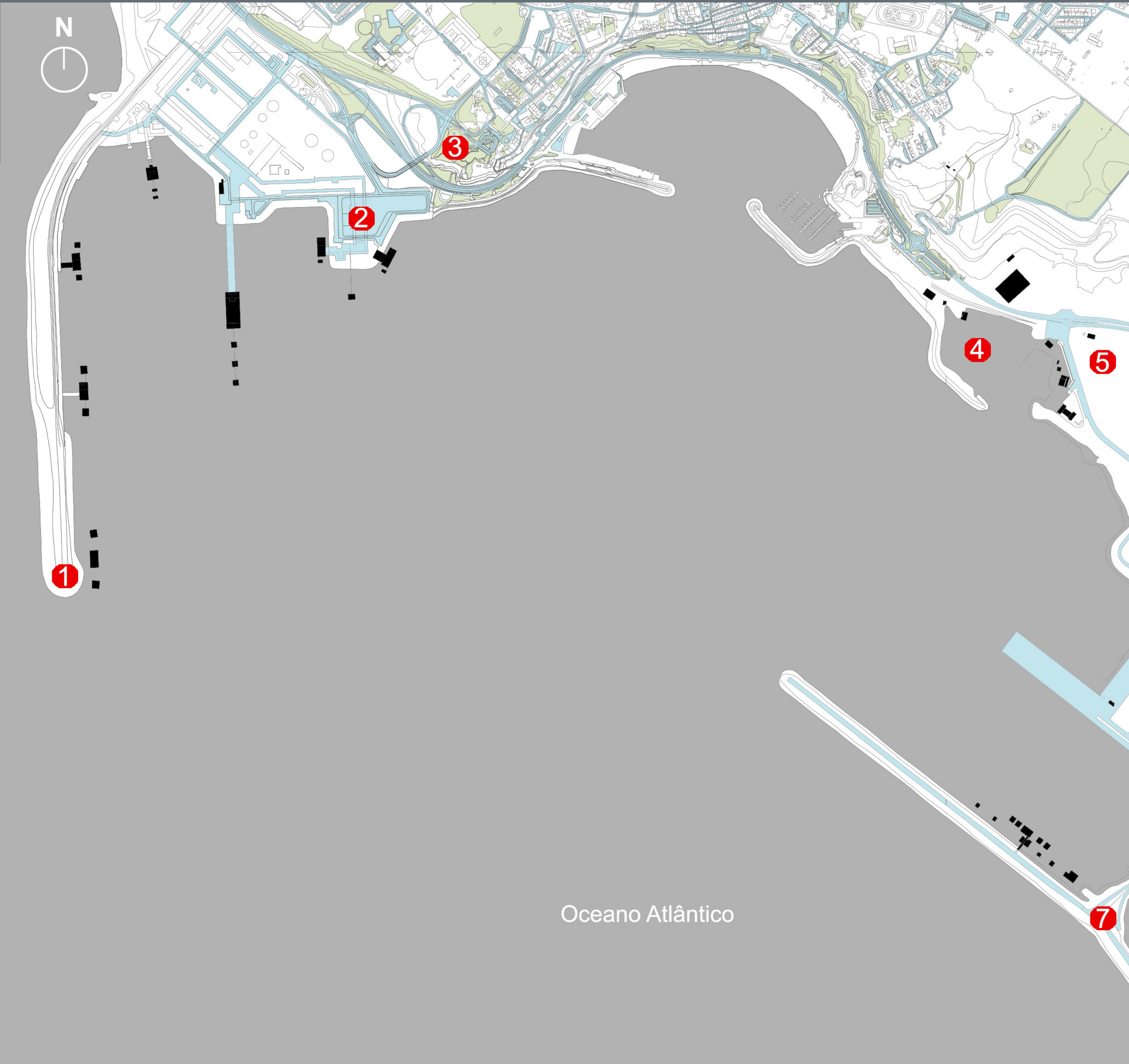
Plano de Urbanização 2008

1. Zona Habitacional a Urbanizar
2. Grande Jardim
3. Habitação Coletiva
4. Urbanização
5. Escola
6. Zona Colectiva
7. Zona Urbanizável
8. Zona Industrial a Consolidar

- Espaço de Recreio e Lazer
- Espaço Industrial
- Espaço Colectivo
- Espaço Habitacional

Fig,24 VISTA AÉREA DO PORTO DE SINES

1. PROPOSTA DE GRUPO



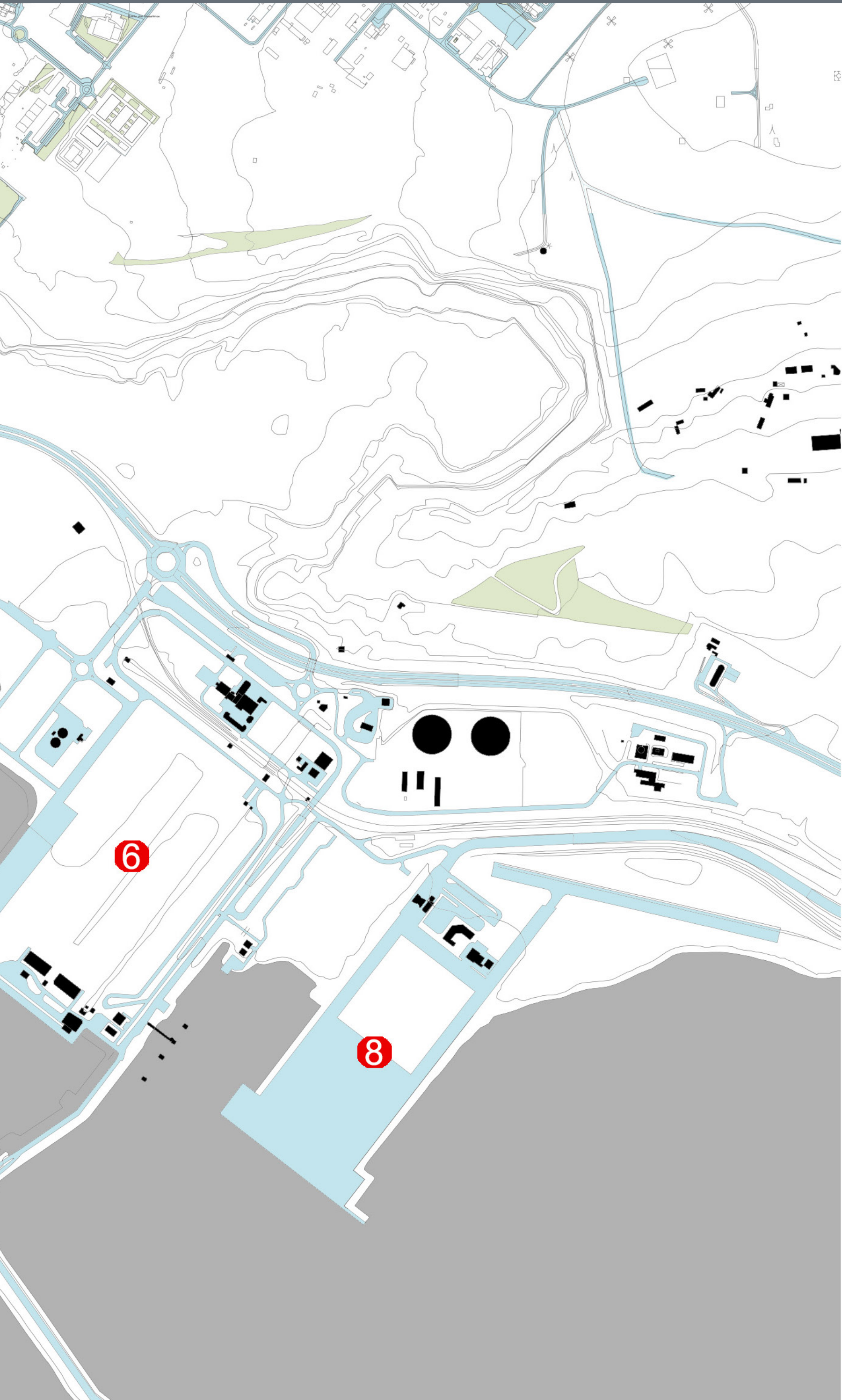


Fig. 25 Evolução do Porto de Sines
O desenvolvimento de Sines sempre se viu associado ao oceano, às atividades marítimas, piscatórias e portuárias. Como tal, a evolução tecnológica do transporte marítimo afectou a cidade, criando em Sines a tendência para o aumento da capacidade de transporte para navios e para a adaptação das infraestruturas.

Porto de Sines

1. Terminal de Granéis Liquidos
2. Terminal Petroquímico
3. Posto de Controlo
4. Porto de Serviços
5. ZAL Sines
6. Terminal Multipropósito
7. Terminal GNL
8. Terminal de Contentores

1.Terminal de Granéis Liquidos

O TGL - Terminal de Granéis Líquidos, inaugurado em 1978, é o maior terminal de granéis líquidos do país, concebido numa arquitetura multicliente e multiproduto. Com seis postos de acostagem e fundos naturais até 28 metros, tem capacidade para receber navios de porte até 350.000 toneladas. [6]

Fig.26 TGL - Terminal de Granéis Líquidos

2.Terminal Petroquímico

Desde 1981 o Porto de Sines dispõe de um terminal dedicado para produtos petroquímicos, o TPQ - Terminal Petroquímico, que permite a movimentação de mercadorias entre os navios e o complexo petroquímico localizado na ZILS - Zona Industrial e Logística de Sines. Este terminal é operado pela Repsol Polímero em regime de concessão de uso privativo.[6]

Fig.27 TPQ- Terminal Pertroquímico

Fig.28 APS - Adminitração do Porto

3.Administração do Porto

A APS - Administração dos Portos de Sines e do Algarve, é a entidade responsável por assegurar o exercício das competências necessárias ao regular funcionamento do Porto de Sines e dos Portos comerciais de Faro e de Portimão nos múltiplos aspetos de ordem económica, financeira e patrimonial, de gestão de efetivos e de exploração portuária e ainda as atividades que lhe sejam complementares, subsidiárias ou acessórias. [6]

Fig.29 Porto de Serviços

4.Porto de Serviços

O Porto de Serviços serve de apoio á atracagem de embarcações do Porto recreativo. Por não estar sob o domínio da APS mas das entidades locais este porto com 2 cais de acostagem pode melhorar significativamente a qualidade da costa sineense. Com 6 metros de profundidade é capaz de alojar Navegações recreativas até 5.000 toneladas. [6]

5.ZAL Sines

A ZALSINES - Zona Industrial e Logística de Sines, constitui-se como uma plataforma logística moderna, com elevado potencial estratégico para serviços de valor acrescentado. Esta vocacionada para a instalação de empresas industriais e de serviços, servida por um sistema rodo-ferroviário de grande capacidade. [6]

Fig.30 ZAL Sines

6.Terminal Multipropósito

O TMS - Terminal Mulpurpose de Sines iniciou a sua exploração em 1992 em regime de concessão de serviço público à empresa Portsines, e está vocacionado para a movimentação de granéis sólidos e carga geral. Pa a movimentação dos granéis líquidos o terminal usufrui de dois pórticos e para a carga geral uma ampla área de cais e de armazenagem. [6]

Fig.31 Terminal Multipropósito

Fig.32 TGN - Terminal de Gás Natural

7.Terminal GNL

O Terminal de Gás Natural iniciou a sua atividade em 2003, e é operado em regime de concessão de uso privativo pela empresa REN Atlântico, movimentando já hoje mais de 50% do Gás Natural consumido em Portugal. É a prinipal fonte nacional de abastecimento deste produto e tem uma enorme importância estratégica a nacional. [6]

Fig.33 Terminal XXI

8.Terminal de Contentores

O Terminal de Contentores de Sines, denominado Termial XXI, iniciou operações em 2004 e é operado em regime de concessão de serviço público pela empresa PSA Sines (PSA - Port Singapore Authority). O terminal XXI oferece fundos naturais até 17 metros, permitindo a acostagem de grandes navios porta-contentores. [6]

A rápida evolução do Porto de Sines tem sido determinante no crescimento da cidade mas o seu futuro permanece alheio á Câmara Municipal criando uma ambiguidade perigosa. Na tentativa de colmatar esta falha e mediar as relações entre o Porto e a Cidade, foram levadas a cabo duas reuniões e discussões com altos comissários do Porto que aprofundaram questões sobre o futuro do Porto de Sines. Das reuniões resultaram vários documentos onde é possível encontrar planos de escala nacional (fig.31) prevendo novos caminhos férreos, até planos de escala local (fig.32) onde podemos verificar as intensões do Porto em expandir o porto de contentores usando a pedreira já amplamente danificada.

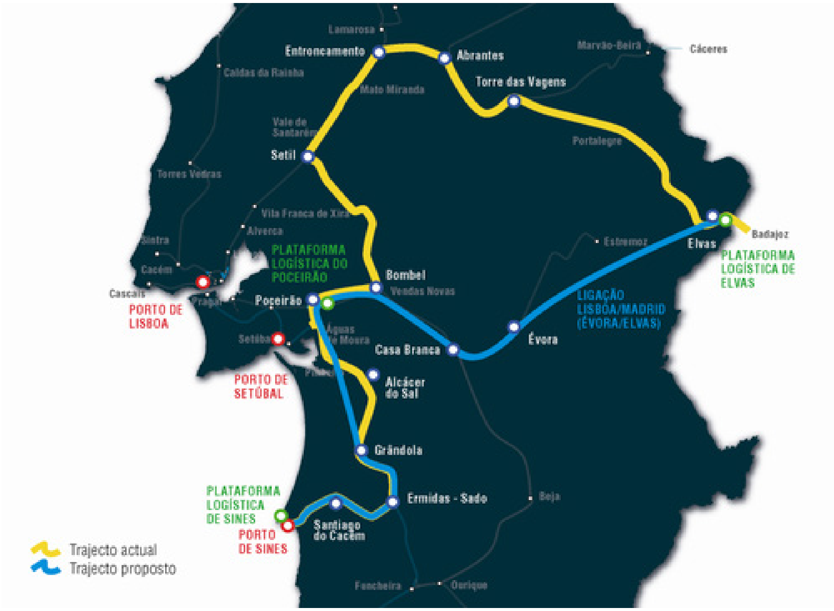


Fig.34 Ligação Sines - Madrid

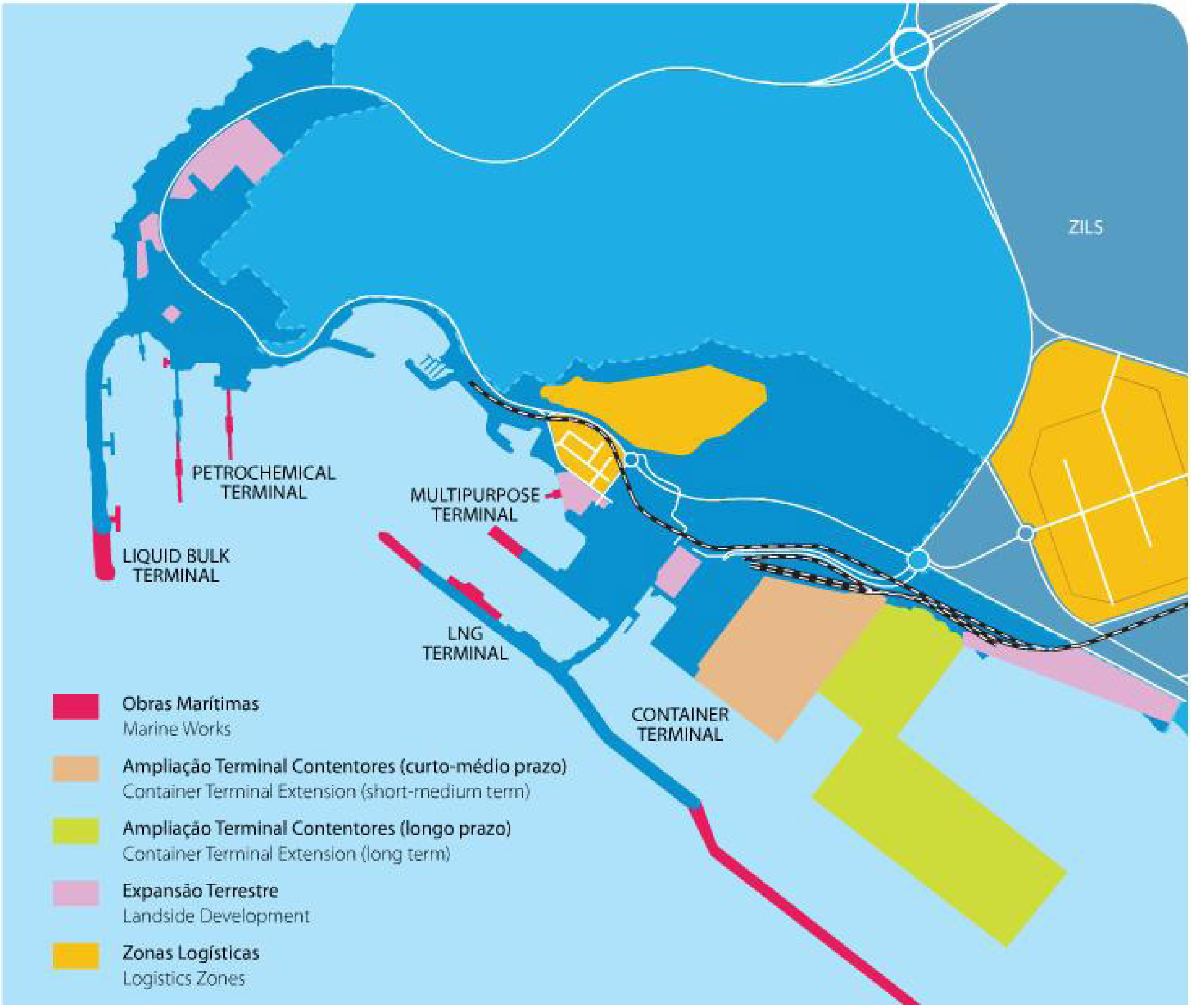


Fig.35 Plano de Expansão do Porto de Sines

1. PROPOSTA DE GRUPO

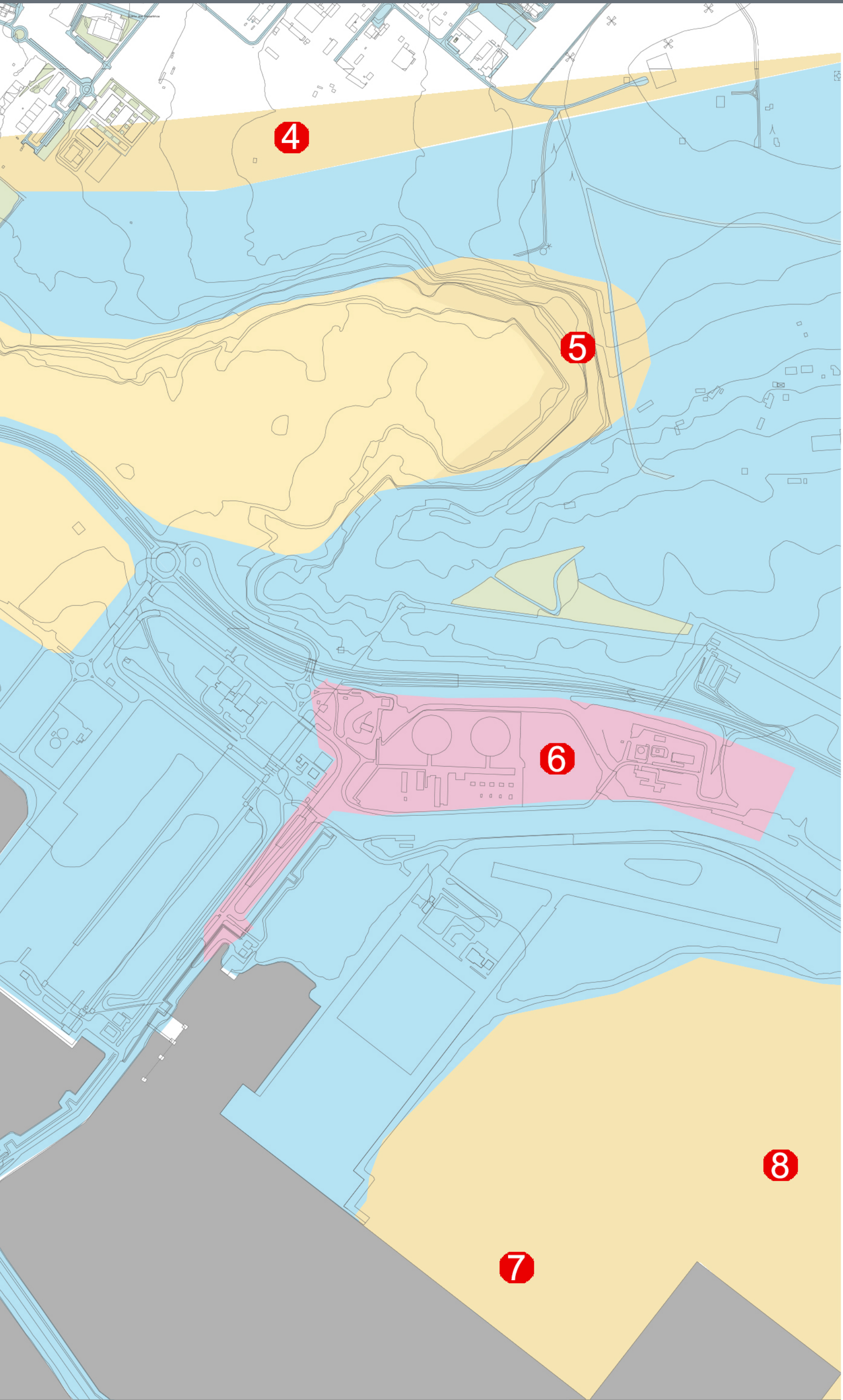


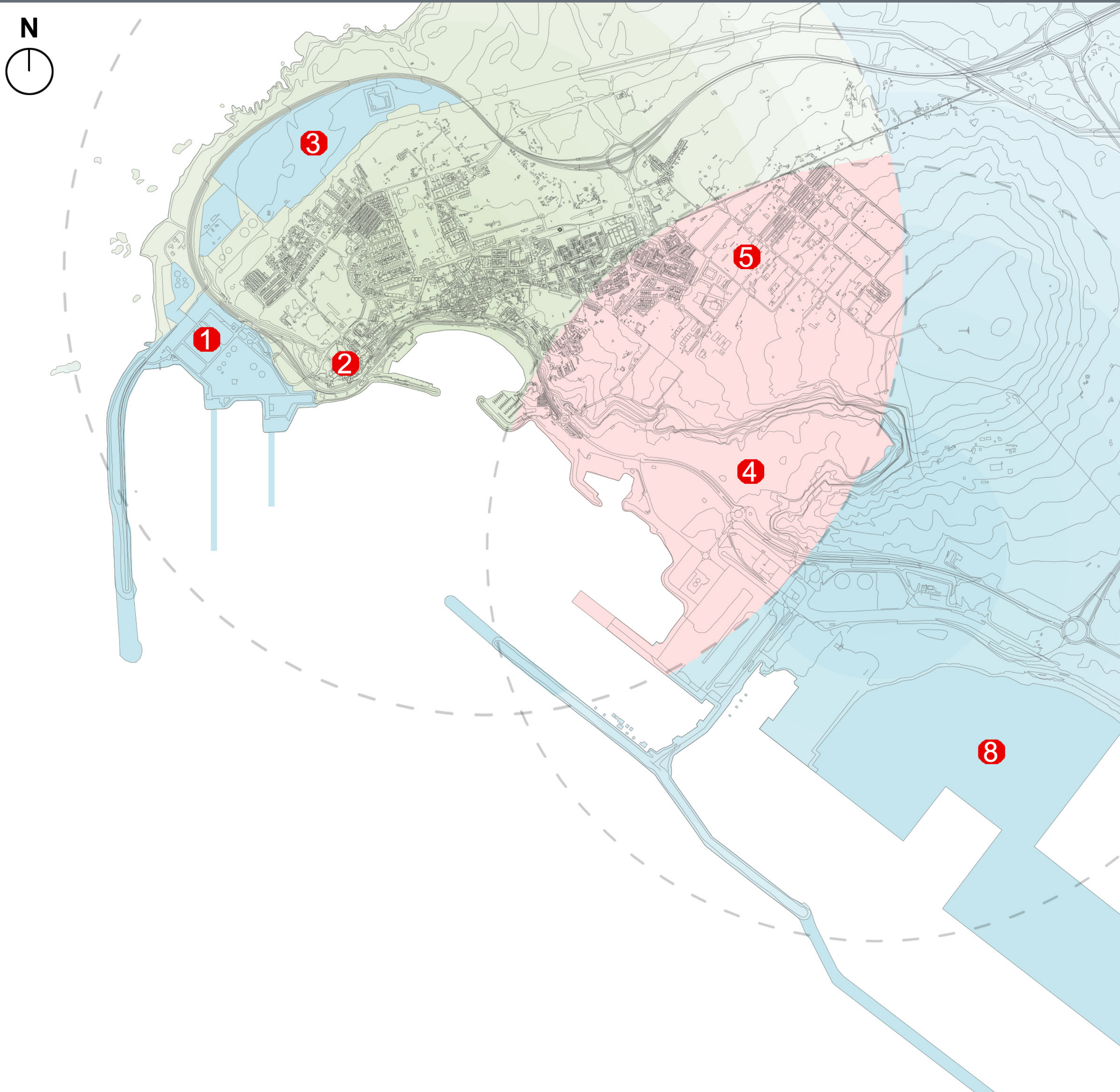
Fig. 36 Expansão do Terminal XXI
Elaborado pela PSA - Port Singapore Authority - o plano de expansão do Terminal XXI do porto de Sines tem evoluído rapidamente. Até agora esta expansão contemplou: um novo cais para navios,, duas gruas móveis e quatro gruas de parque. Estas infraestruturas aumentar a capacidade do terminal de 1,7 milhões de TEUS para 2,5 milhões. [6]

Sines XXI

1. Expansão do Terminal de G.Líquidos
2. Espansão do Molho
3. Espansão do Terminal Multipropósito
4. Expansão da Juristição Terrestre
5. Exploração da Pedreira
6. Expansão do Armazenamento
7. Alargamento da Plataforma
8. Expansão da Área de Contentores

Juritição Terrestre do Porto
Zona de Armazenamento
Zona de Logística
Zona de Expansão

1. PROPOSTA DE GRUPO



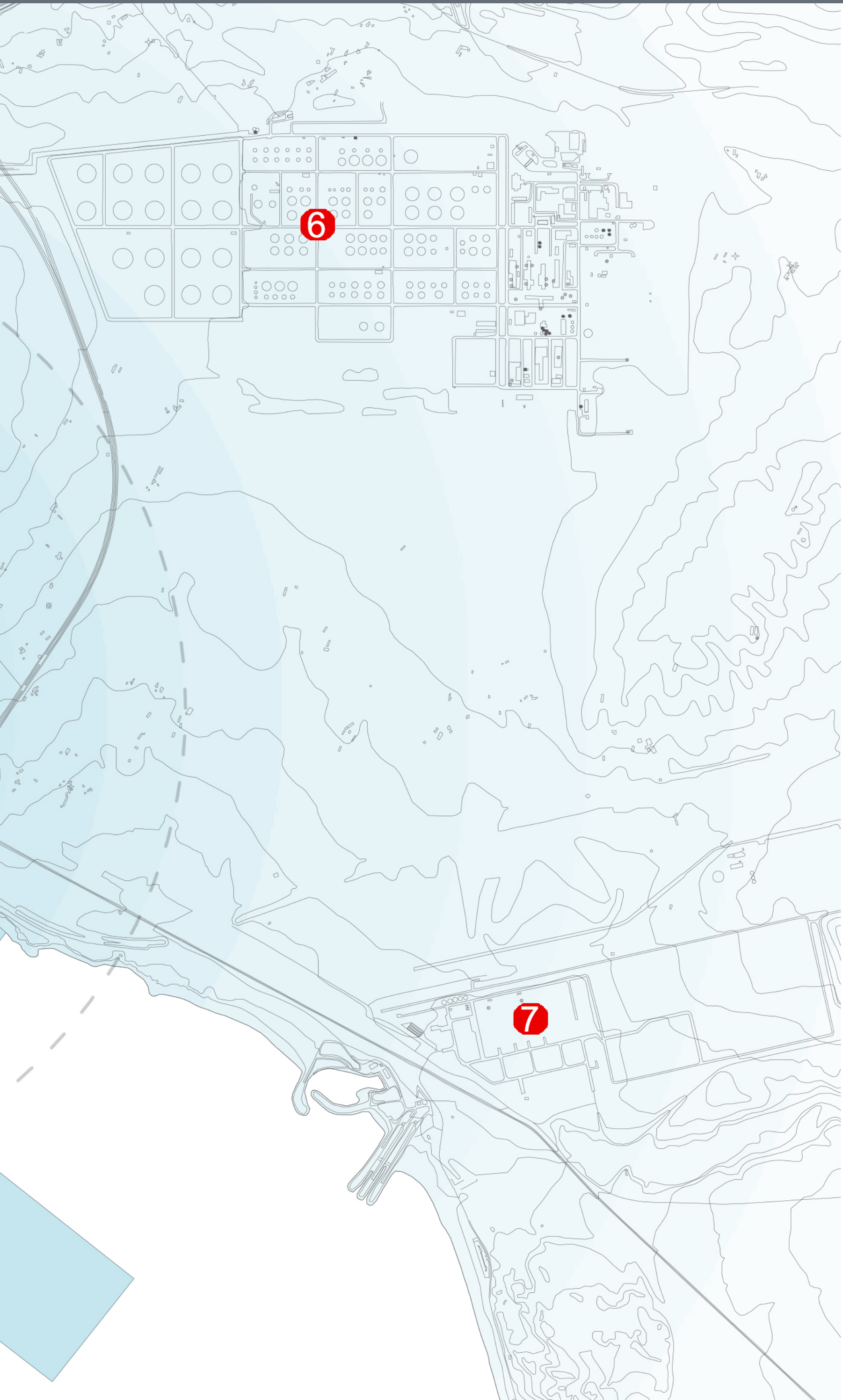


Fig. 37 Conflito

Os dois planos de expansão criam uma zona de conflito que ilustra a ausência de dialogo entre as entidades locais e o porto. Para a frente-mar existem já planos de expansão urbana da cidade bem como de expansão das concessões atribuídas ao projeto Terminal XXI.

Visão para o Porto de Sines

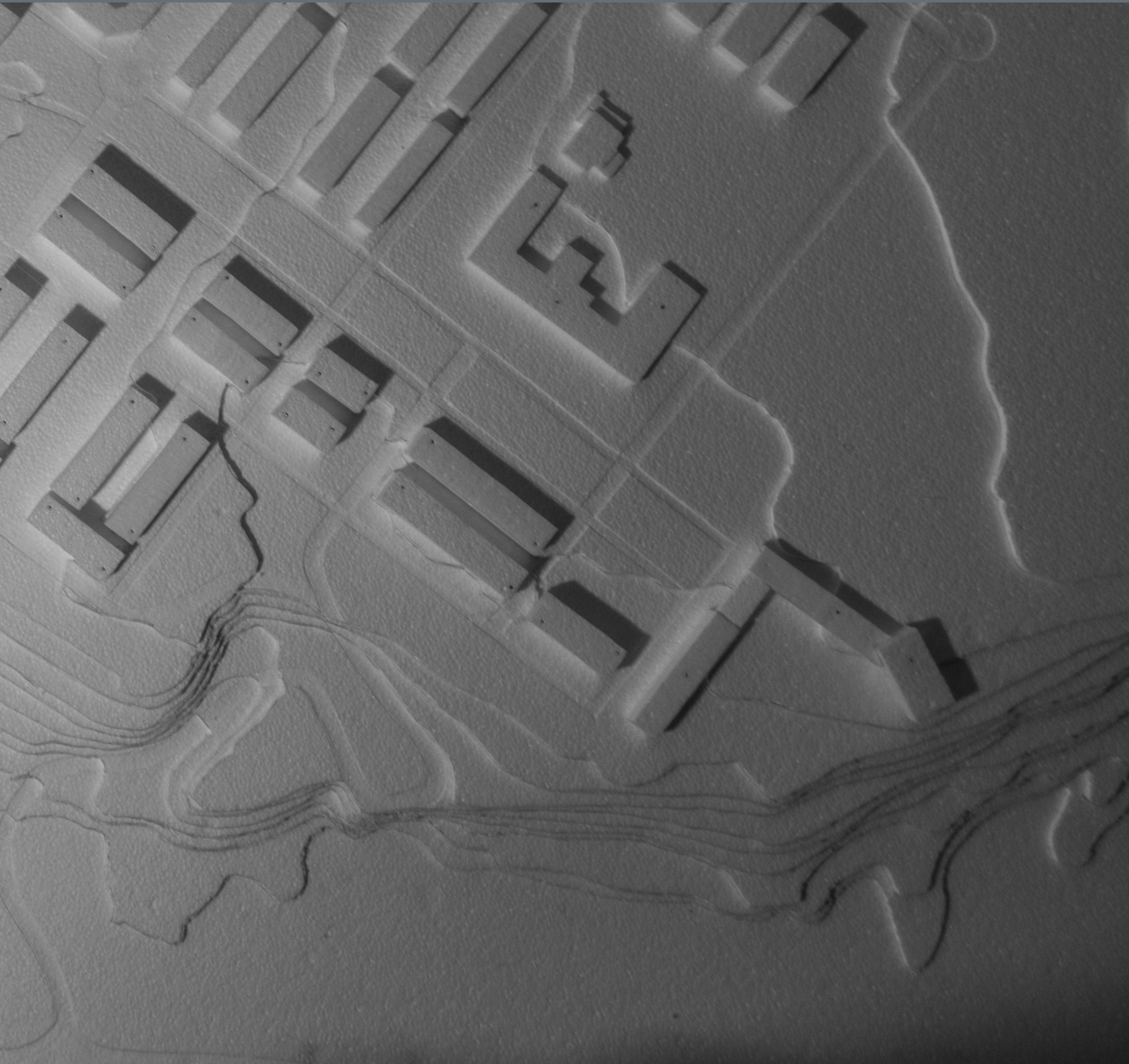
1. Terminal de Granéis Liquidos
2. Posto de Controlo
3. Gestão de Resíduos
4. Pedreira / Zona Logística
5. Zona Empresarial
6. Zona Industrial
7. Refinaria de Carvão
8. Terminal de Contentores

Jurisdição Terrestre da Cidade

Conflito

Jurisdição Terrestre do Porto

Fig,38 MAQUETE DE GRUPO



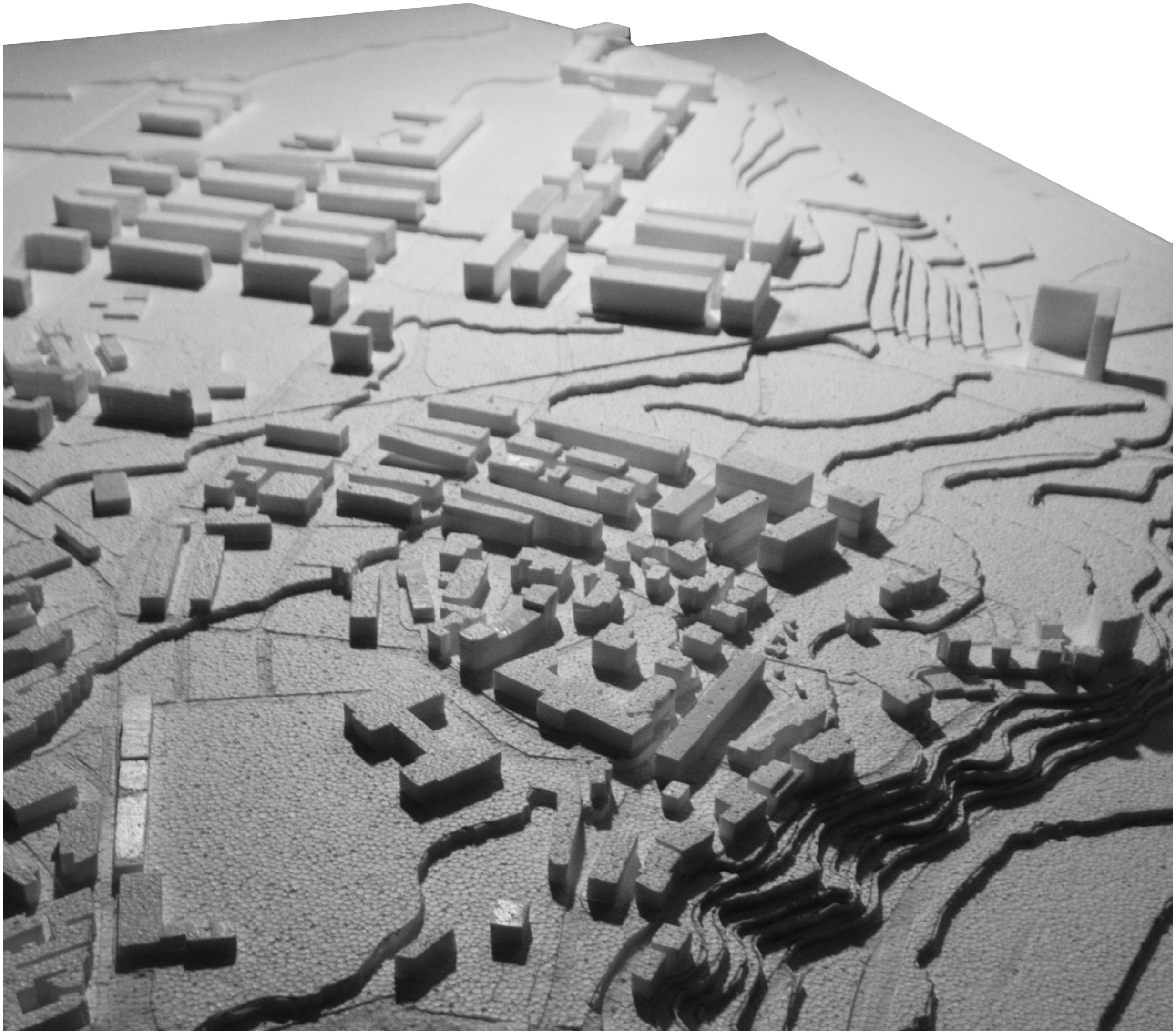


Fig.39 Fotografia da Maquete de Grupo

3. Estatégia de Intervenção

A análise feita em preparação para o desenvolvimento da estratégia de intervenção permitiu entender que nas três últimas décadas a cidade e o porto têm trabalhado autonomamente com agendas distintas, e muitas vezes dispares, criando uma série de carências nos pontos de contacto com a terra, onde as infraestruturas estão desatualizadas e aquém do potencial sineense. A falta de investimento em infraestruturas que satisfizessem as necessidades da população tiveram fortes implicações sociais na cidade e contribuíram para um "sentido de invasão" generalizado que tem vindo a comprometer o contacto entre cidade e porto desde os anos 80. Procurando reconciliar esta relação e suportar o crescimento previsto para o Terminal XXI durante os próximos 15 anos, uma estratégia de reconciliação foi desenvolvida pelo grupo procurando redefinir limites atualmente difusos entre a cidade e o porto.

Sendo a pedreira o elemento comum entre os dois agentes, grande parte do exercício foi desenvolvido no sentido de aproximar os limites da cidade á pedreira, potencialmente até incluindo-a no seu domínio. (fig.35) De certa forma, a lógica base desta abordagem parece tomar o lado da cidade e parece até renunciar o Porto, no entanto, isto não é senão uma consequência das várias fases de pensamento de um exercício que tentou ao longo de todas as fases ser dotado de imparcialidade e compreensão de parte a parte. A resposta final pode ser vista como uma solução equilibrada em que a cidade beneficia do Porto tanto como o Porto da cidade.

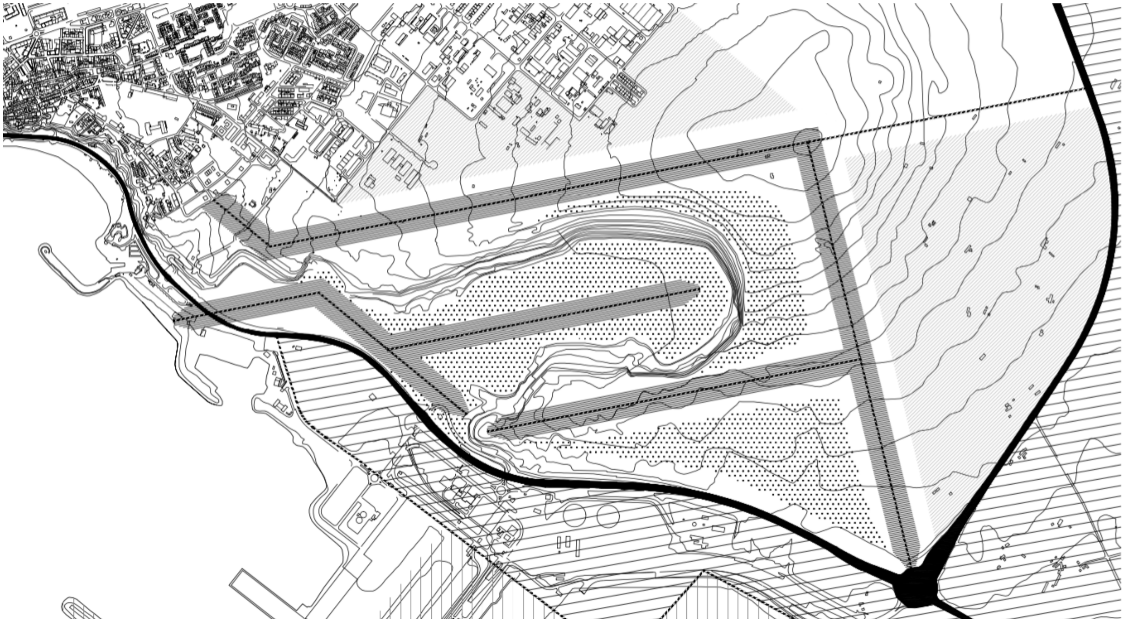


Fig.40 Estudo inicial de expansão (eixos e concessões)

Na sequência do estudo inicial, elaborou-se uma proposta (fig.36) que tentava incluir a pedreira e reclamá-la para a cidade. Esta ideia serve de base á proposta final mas abandonou-se por se ter descoberto que dificilmente se poderia regenerar a pedreira para uma situação mais favorável do que aquela em que se encontra, provocando conflitos desnecessários com o Porto.

Fig.41 Estudo dos principais eixos de expansão.

Ainda nesta lógica houve uma ponderação grande relativamente ao carácter dos eixos de expansão, sobre como poderiam provocar o crescimento da cidade em seu redor. Várias alternativas foram ponderadas e determinou-se ser desejável que estes eixos fossem corredores verdes, capazes de mover grandes fluxos de pessoas até ao limite da pedreira, dotando esta borda com equipamentos pontuais que alimentassem a consciência dos residentes, unindo-os numa força a ser respeitada pelo Porto. Como é lógico esta é uma abordagem altamente conservadora e por essa razão foi abandonada, no entanto houve uma reflexão interessante sobre o carácter de um eixo, resultando numa proposta genérica. (fig. 37)

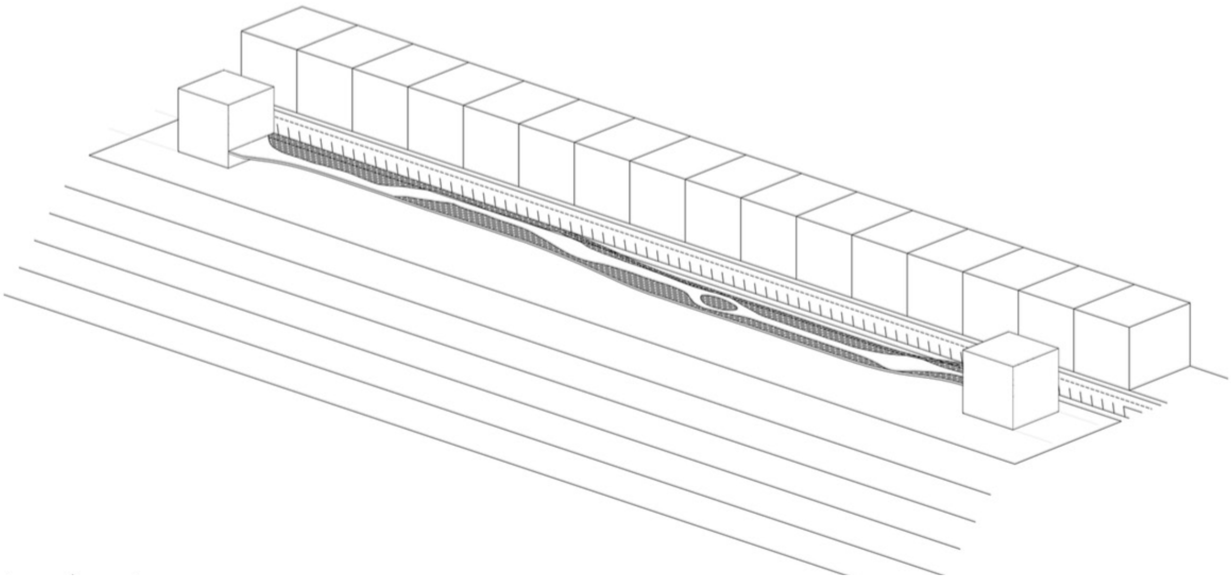


Fig.42 Estudo de porção do eixo de expansão.

A fase final da estratégia consiste em trabalhar apenas um dos eixos, na esperança que os outros acompanhem o desenvolvimento em fases posteriores. Ao reclamar a frente-mar esta proposta cumpre o mesmo propósito de defender a cidade mas pressupõe um discurso mais complacente com o Porto. A proposta final (fig. 38) será aprofundada no capítulo seguinte com contextualização mais apropriada.

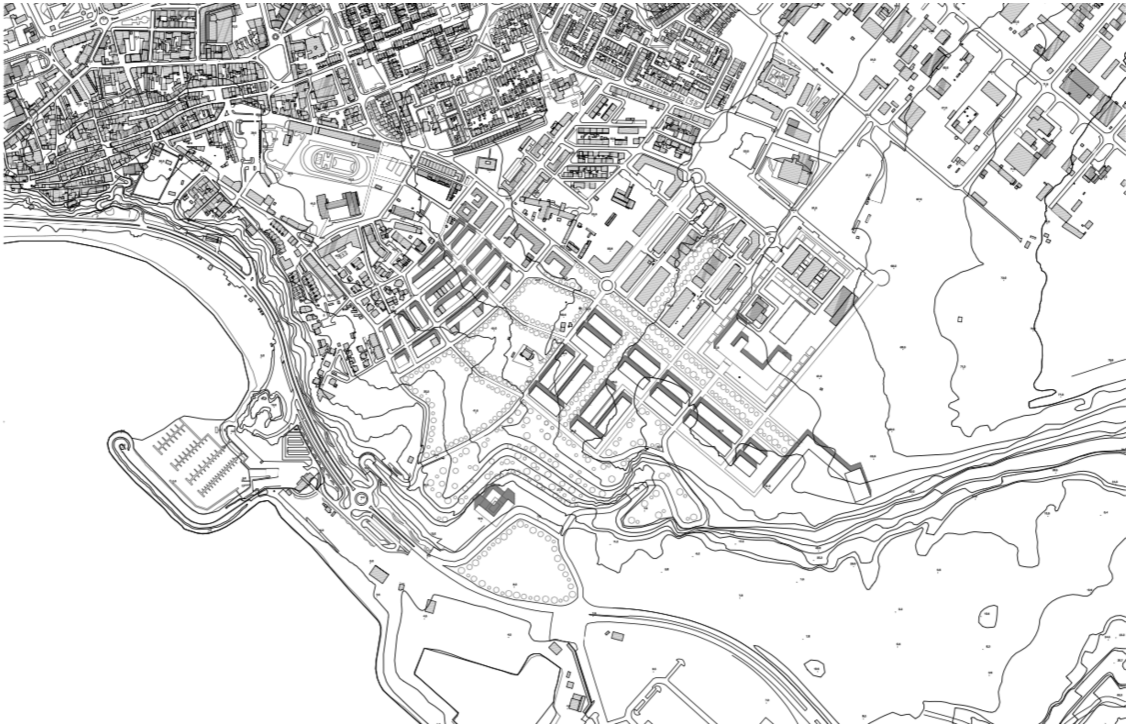


Fig.43 Proposta Final de expansão.

1. PROPOSTA DE GRUPO

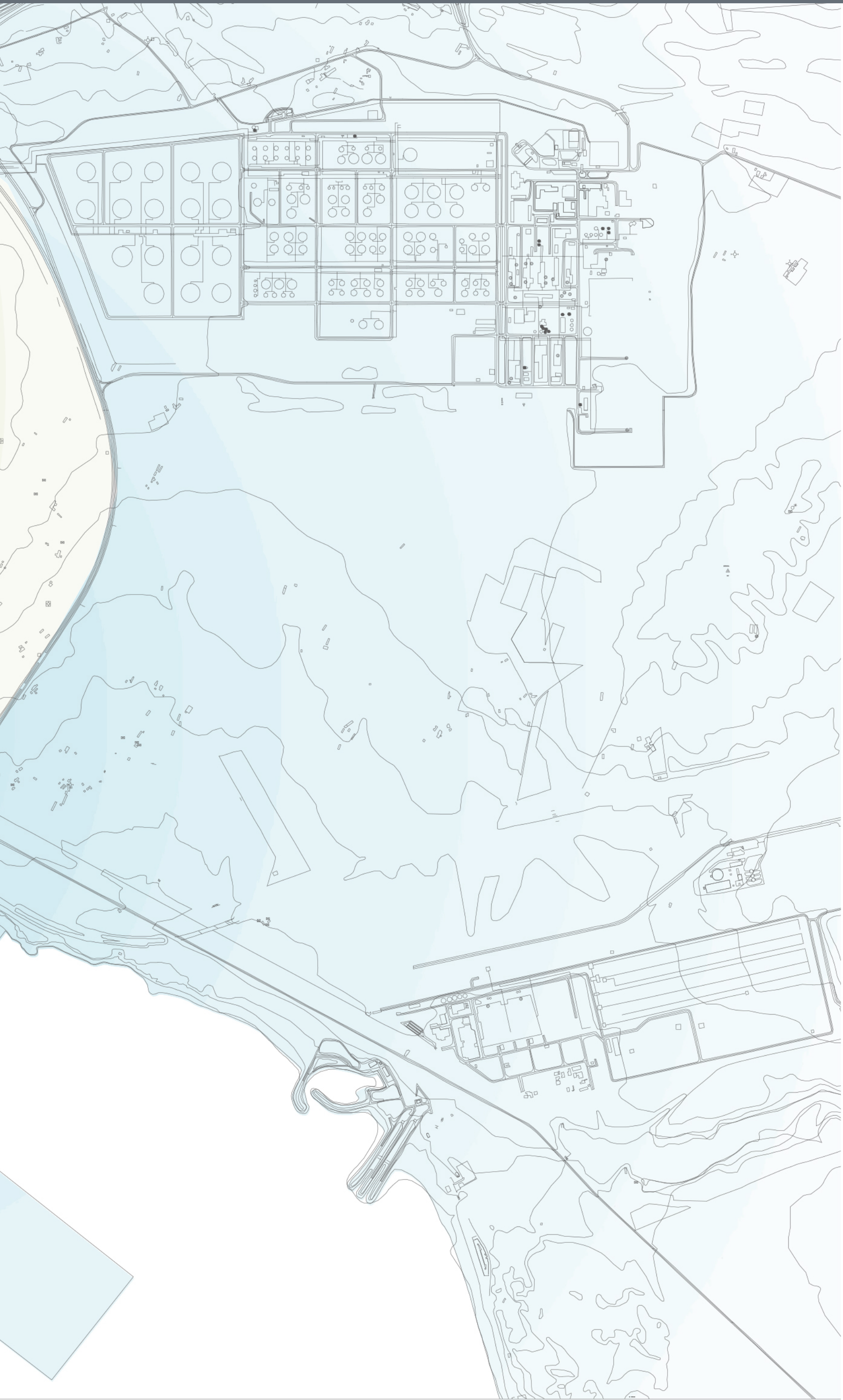


Fig.44 Reatribuição de Concessões

A proposta de grupo sugere que a parte alta da cidade seja totalmente atribuída ás entidades locais, cedendo a parte baixa e toda zona a Este da estrada A26-1 ao Porto. Pensa-se que desta forma a cidade pode beneficiar do crescimento da entidade portuária e vice-versa.

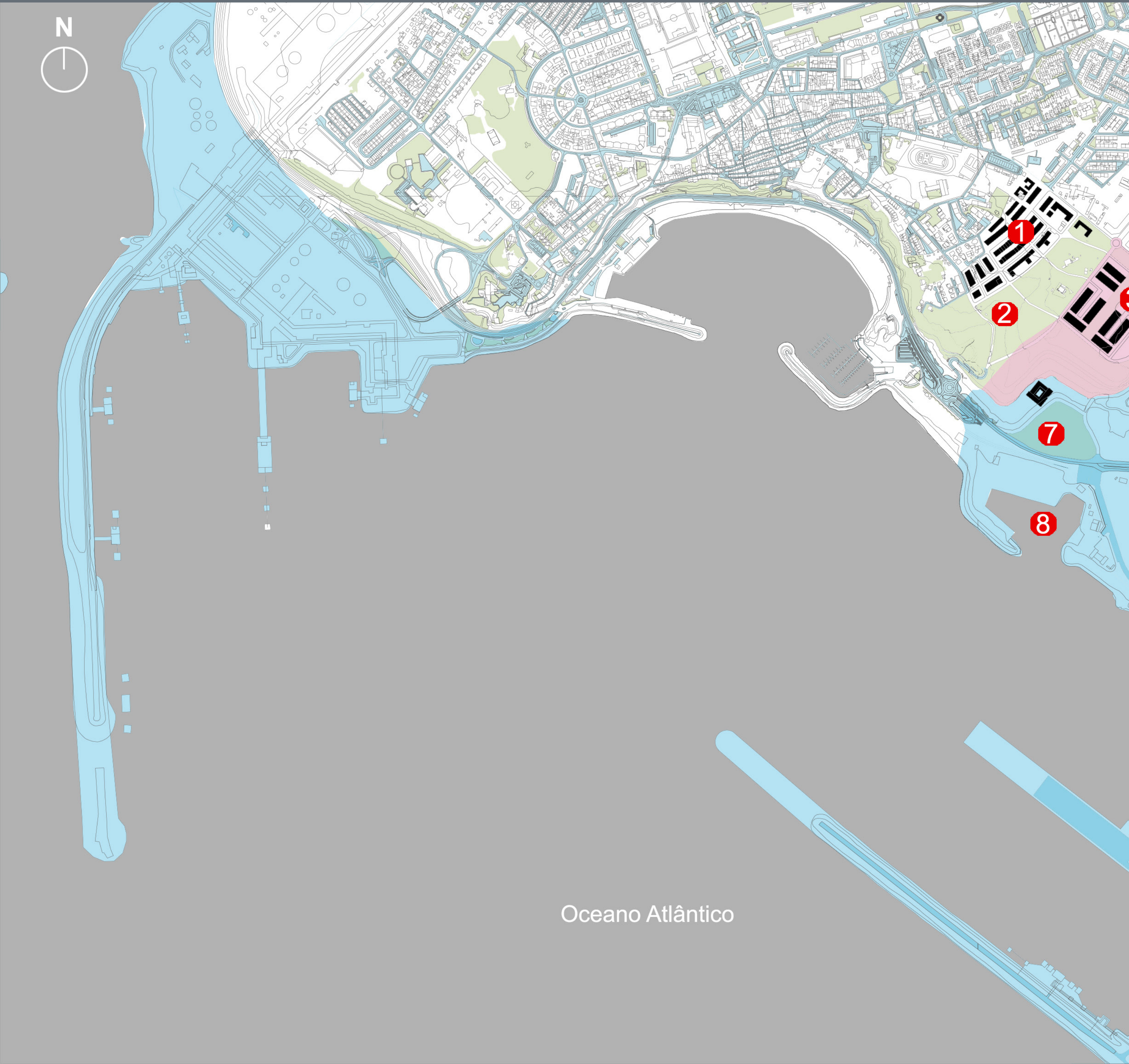
Proposta de Reconciliação

1. Finalizão do Tecido Urbano Antigo
2. Requalificação da Zona Verde
3. Construção de Habitações Coletivas
4. Nova Escola de Música e Dança
5. Nova Escola Profissional
6. Expansão da Zona Empresarial
7. Cedência de Novo Hotel de Negócios
8. Cedência do Porto de Serviços

Jurisdição Terrestre da Cidade

Jurisdição Terrestre do Porto

1. PROPOSTA DE GRUPO



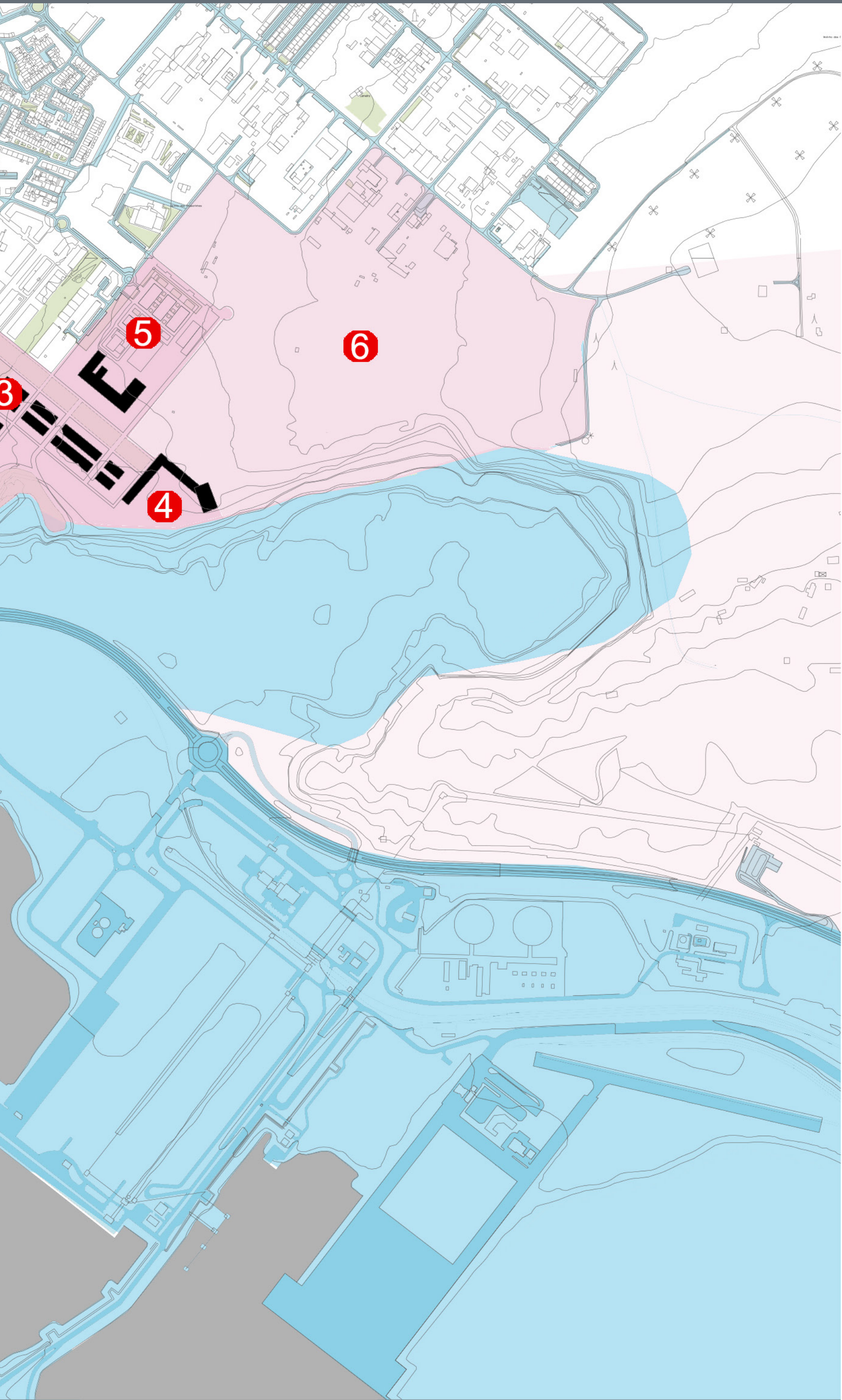


Fig.45 Fases de Expansão Urbana

A proposta de expansão inicia-se no limite da cidade histórica e adapta-se á porção do plano já construída. As fases 2 e 3 contemplam o assentamento de empresas e devem desenvolver-se em paralelo com a zona habitacional de forma a impedir a exploração da pedreira após a construção do Terminal XXI.

Proposta de Reconciliação

1. Finalizão do Tecido Urbano Antigo
2. Requalificação da Zona Verde
3. Construção de Habitações Coletivas
4. Nova Escola de Música e Dança
5. Nova Escola Profissional
6. Expansão da Zona Empresarial
7. Cedência de Novo Hotel de Negócios
8. Cedência do Porto de Serviços

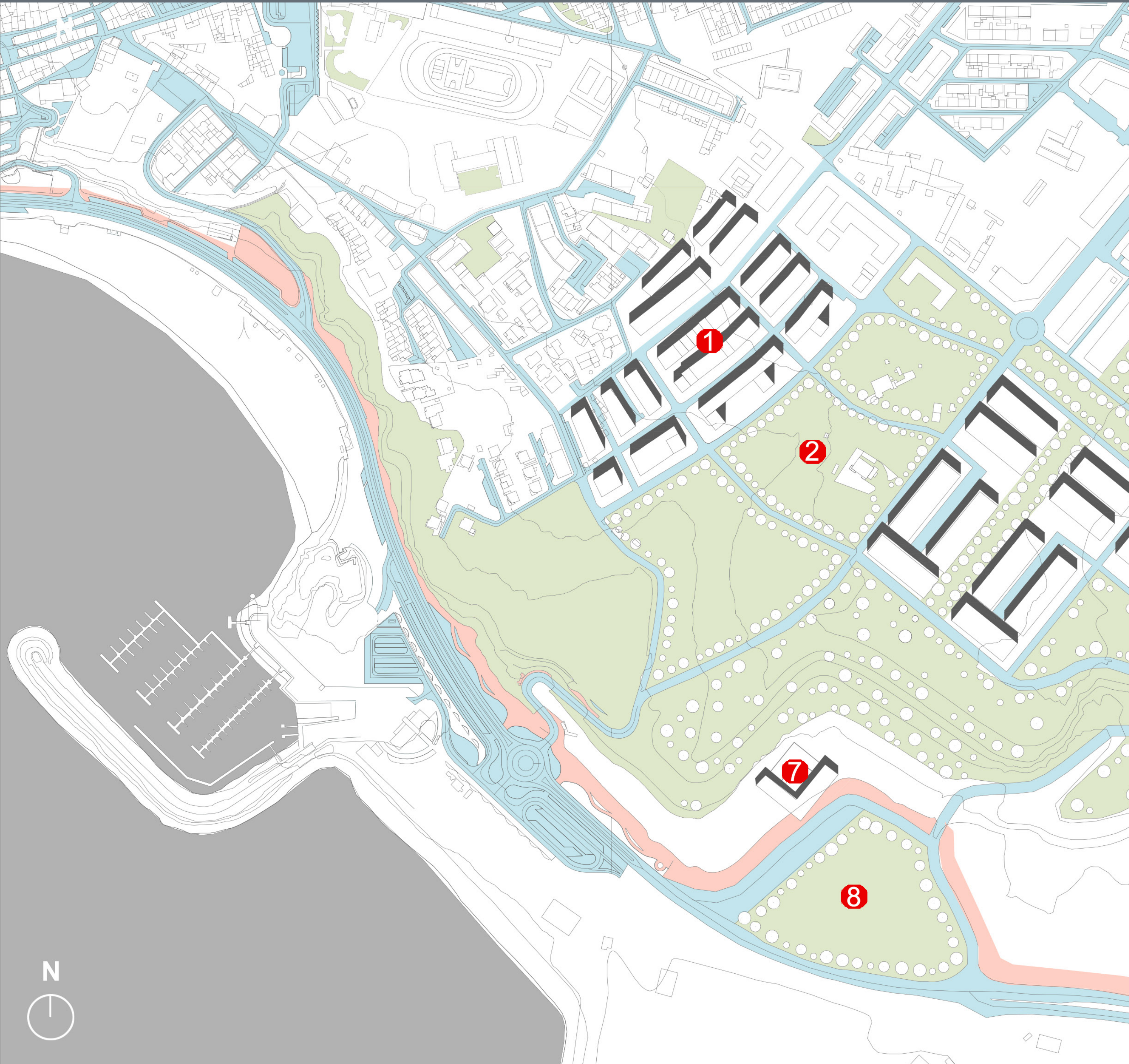
Expansão Urbana Fase 3

Expansão Urbana Fase 2

Expansão Urbana Fase 1

Jurisdição Terrestre do Porto

1. PROPOSTA DE GRUPO



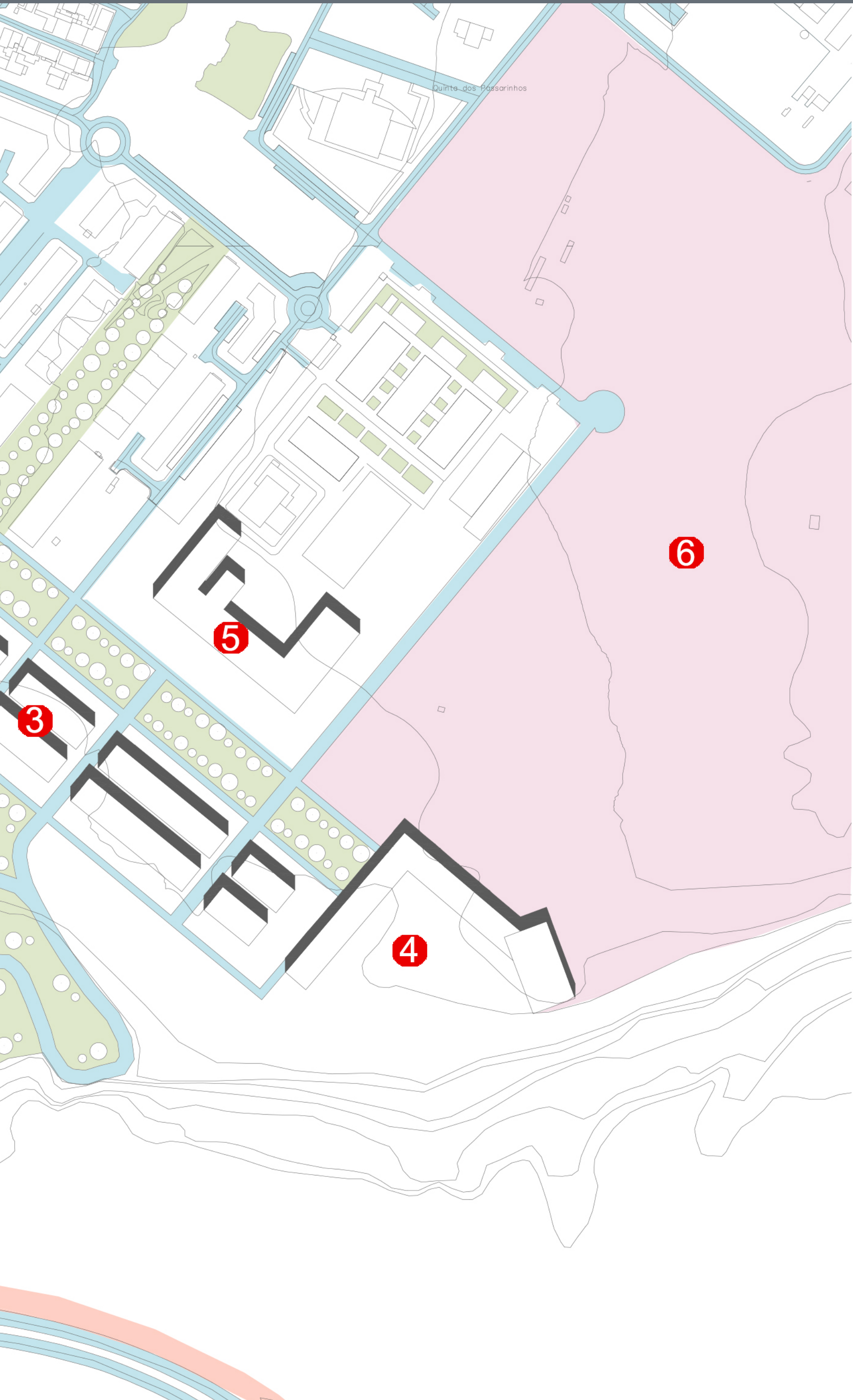


Fig. 46 Distribuição Programática
Para modernizar o tecido urbano foram implantadas várias habitações coletivas, uma escola profissional, uma escola de música e um hotel, bem como duas alamedas verdes que percorrem todo o plano. As relações de proximidade entre zona empresarial, educativa, habitacional portuária e de lazer saem assim fortalecidas acrescentando valor á cidade.

Proposta Urbana

1. Finalizão do Tecido Urbano Antigo
2. Requalificação da Zona Verde
3. Construção de Habitações Coletivas
4. Nova Escola de Música e Dança
5. Nova Escola Profissional
6. Expansão da Zona Empresarial
7. Novo Hotel de Negócios
8. Jardim

Zona Empresarial

Ciclovia

Zonas Verdes

Via de Trânsito

Fig.47 VISTA DA MAQUETE DE GRUPO

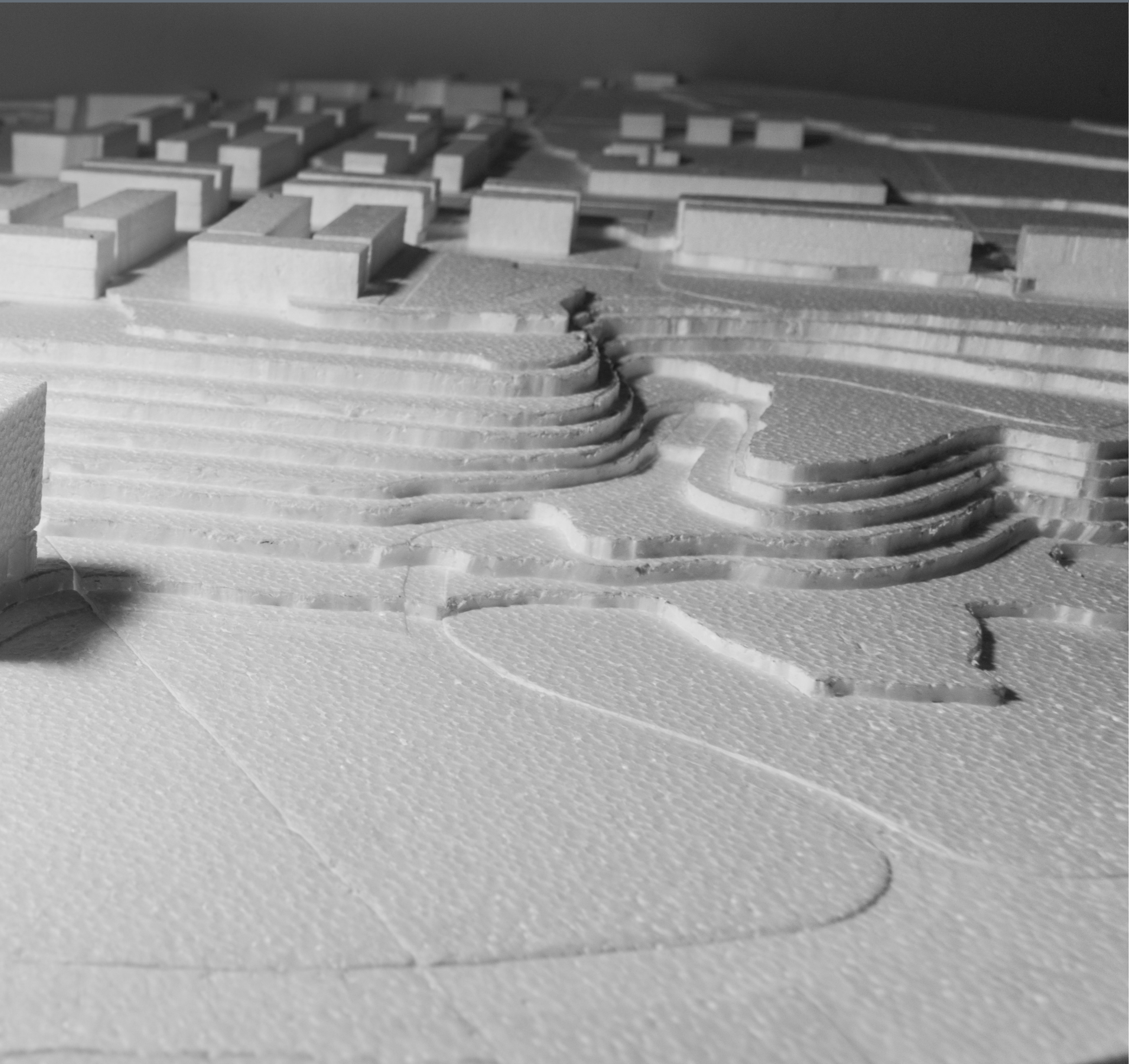


Fig.48 Fotografia do local de Intervenção

1.Localização

A área de intervenção proposta no plano de grupo é fundamentalmente caracterizado pelas duas alamedas verdes, principais orientadoras do desenvolvimento urbano. Envolvidas por habitações coletivas estes dois eixos escoam simbolicamente em dois edifícios, cada um deles, representativos da cidade e do porto. O eixo pricipal do plano inicia-se na rua mais antiga da cidade (Rua __) e foi prolongado em direcção ao limite da pedreira vendo-se finalizado por uma escola de dança e teatro, representativa da forte aposta na cultura e nas artes de Sines. Contrariamente, o eixo transversal a este, que se vê iniciado a Norte-Nascente, pela estrada da ZIL 2, é terminado por um Hotel, ilustrativo do empreendorismo inerente á entidade Portuária. Com ventos predominantes a N no Outono e a NW no resto do ano, a localização escolhida para a implantação do maior edifício do plano de urbanização proposto é caracterizado pela envolvente arborizada na ordem dos 50 metros (altura média da cidade) capaz de abrigar o edifício dos ventos dominantes.

Na proposta de grupo foram determinados 3 momentos fundamentais, nomeadamente: uma escola profissional, com o intuito de dotar os jovens com faculdades para trabalhar na cidade portuária, uma escola de teatro e dança, para apoiar a forte aposta no carácter cultural de Sines, e um hotel, para apoiar negociações com entidades internacionais. O terreno do hotel (fig.43) está no fim da ciclovia de Sines (fig.44) e caracteriza-se pela envolvente arborizada e por um muro (fig.45)que estabelece a plataforma elevada onde se escolheu implantar o edifício.

Fig.49 Local de Intervenção

Fig.50 Fotografia do Muro Pré-existente

Fig.51 Ciclovia para o local

Fig.52 Organigrama

2. Programa

A vocação de Sines para servir de *winterland* às grandes rotas marítimas mundiais promove a instalação de empresas industriais e de serviços na região. As condições reunidas pelo Terminal XXI são de excelência e por essa razão está previsto que muitas empresas se mudem para Sines. Para alojar estas equipas e promover a sua cooperação na celebração de contractos e projetos, este hotel servirá de apoio ao equipamento da APS na outra ponta da cidade. Está equipado com salas de reuniões, auditórios, uma galeria, um ginásio, uma piscina, saunas, um café, um restaurante, 126 quartos e 95 lugares de estacionamento.

A vocação especial do Hotel exigiu refletir sobre os espaços que poderiam ser necessários para lhe conferir o carácter de negócios sem descurar nos serviços essenciais para o funcionamento de um hotel. O programa a que as primeiras propostas se vinculam é o seguinte:

Piso 0	**Áreas**
Piscinas	500m2
Ginásio	225m2
Salas Terapêuticas	150m2
Balneários	100m2
Administração	100m2
Vestíbulos	50m2
Saunas	25m2
Banho Turco	25m2
Piso 1	
Restaurante	400m2
Sala de Espetáculos	250m2
Cozinha	200m2
Sala de Jogos	150m2
Bar	125m2
Piso Tipo	
Quartos Individuais	20m2
Suites	55m2
Exterior	
Piscina	
Estacionamento	

As primeiras abordagens ao problema desenvolveram-se me paralelo com o trabalho de grupo e tentavam descobrir a melhor posição para o edifício bem como para as circulações verticais, sabendo de antemão que o edifício iria aproveitar a cota baixa e a arriba envolvente para se elevar até aos 40 m.

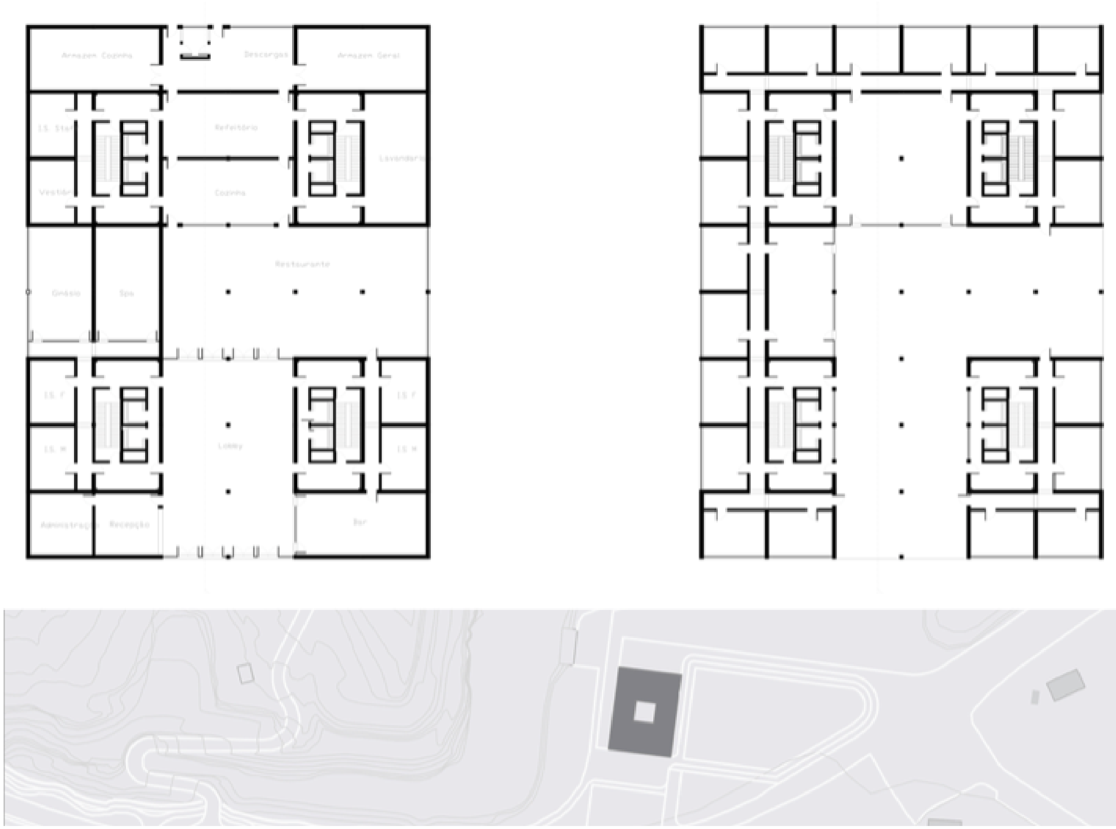


Fig.53 Estudo urbano e de circulações verticais.

Depois de apuradas as posições mais adequadas para o edifício e para as circulações verticais o foco foi para a distribuição programática e qualidade espacial do edifício, dando origem as primeiras linhas gerais do projeto. As propriedades do alçado começaram também a ser trabalhadas com o intuito de reduzir o impacto do edifício na sua envolvente.

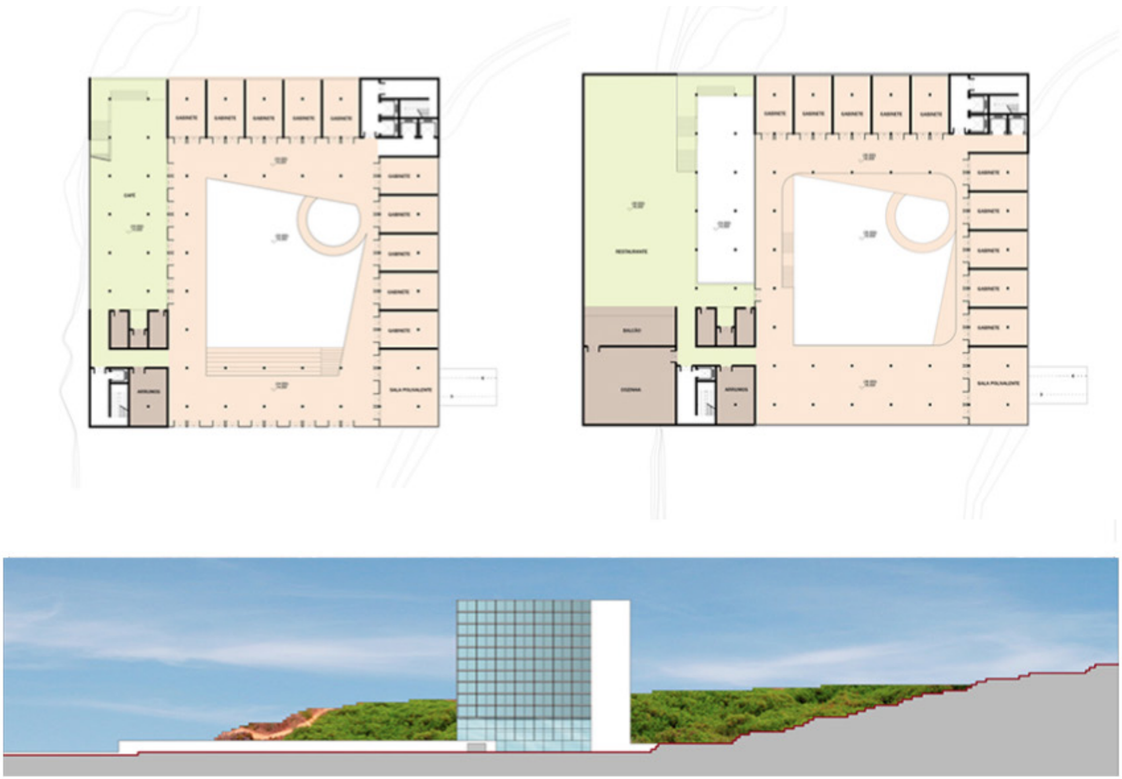


Fig.54 Estudo programático e alçado sudeste.

Chegaram a considerar-se fachadas alternativas com varandas ajardinadas, no entanto o aspecto orgânico acabou por se revelar pior do que a condição anterior. Nesta versão começaram a estudar-se elementos do arranjo exterior como a piscina e circulação viária.

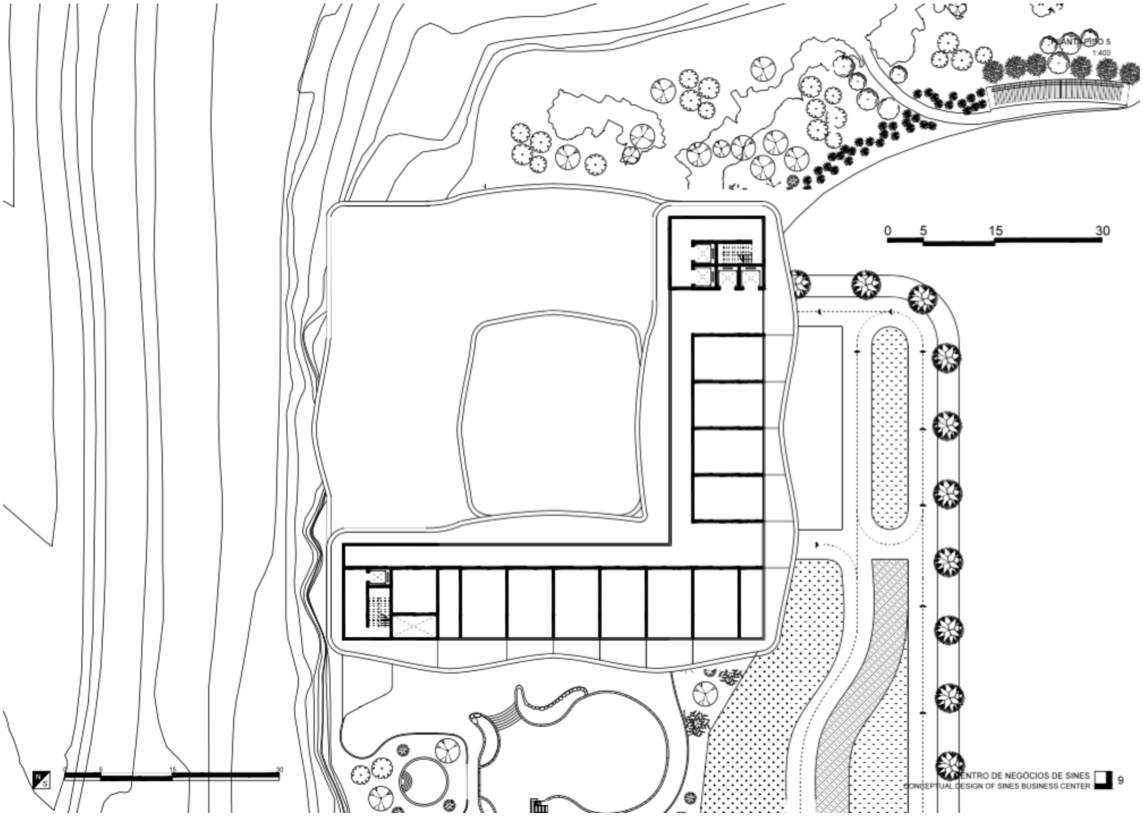


Fig.55 Estudo de envolvente.

A ineficácia da proposta anterior em criar um arranjo exterior satisfatório estabeleceu o mote para a proposta que se seguiu (fig.49), que procurava criar uma unidade entre o edifício e o arranjo exterior. Esta estratégia porém revelou-se também ineficaz, na medida em que o resultado final se assemelha a uma espécie de condomínio privado.

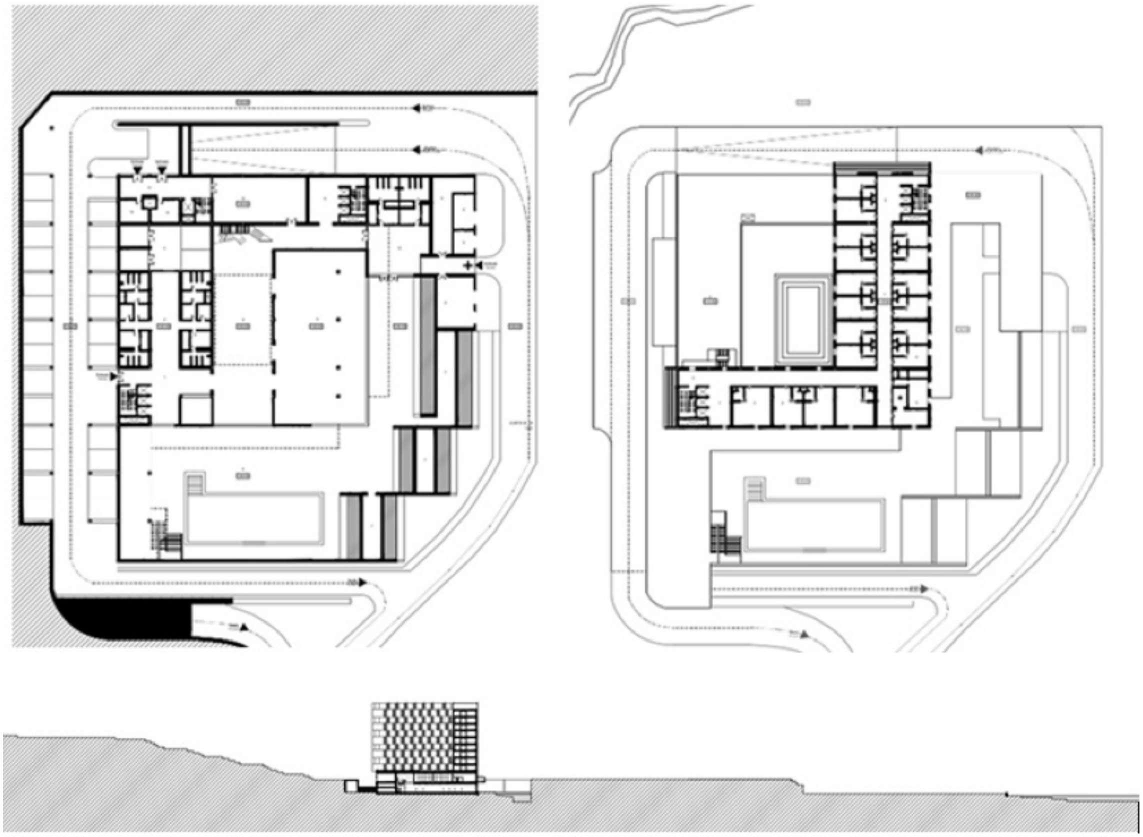


Fig.56 Estudo de integração do edifício no arranjo exterior.

Os estudos que antecedem a proposta final testaram várias alternativas e cada versão, de maior ou menor contribuição, serviu para criar uma proposta adequada ao local, capaz de servir os interesses da cidade e do Porto. O programa final a que a proposta se vincula é o seguinte:

Piso 0	**Áreas**
Átrio de Entrada	650m2
Salas de Reunião	350m2
Casas de Banho	75m2
Economato	190m2
Cargas e Descargas	265m2
Ginásio	135m2
Saunas	85m2
Balneários	135m2
Piso 1	
Salas Polivalentes	230m2
Galeria	650m2
Bar	280m2
Esplanada	280m2
Cozinha	180m2
Piso Tipo	
Suites	25m2
Suites Presidenciais	60m2
Exterior	
Piscina	935 m2
Estacionamento	95 Lugares

A proposta final (fig.50), explorada em detalhe no próximo capítulo, estabelece o limite a partir do qual se distinguem as concessões. Ilustrativo do dialogo harmonioso entre cidade e Porto este edifício é um elemento simbólico da estratégia urbana proposta pelo grupo.

Fig.57 Implantação

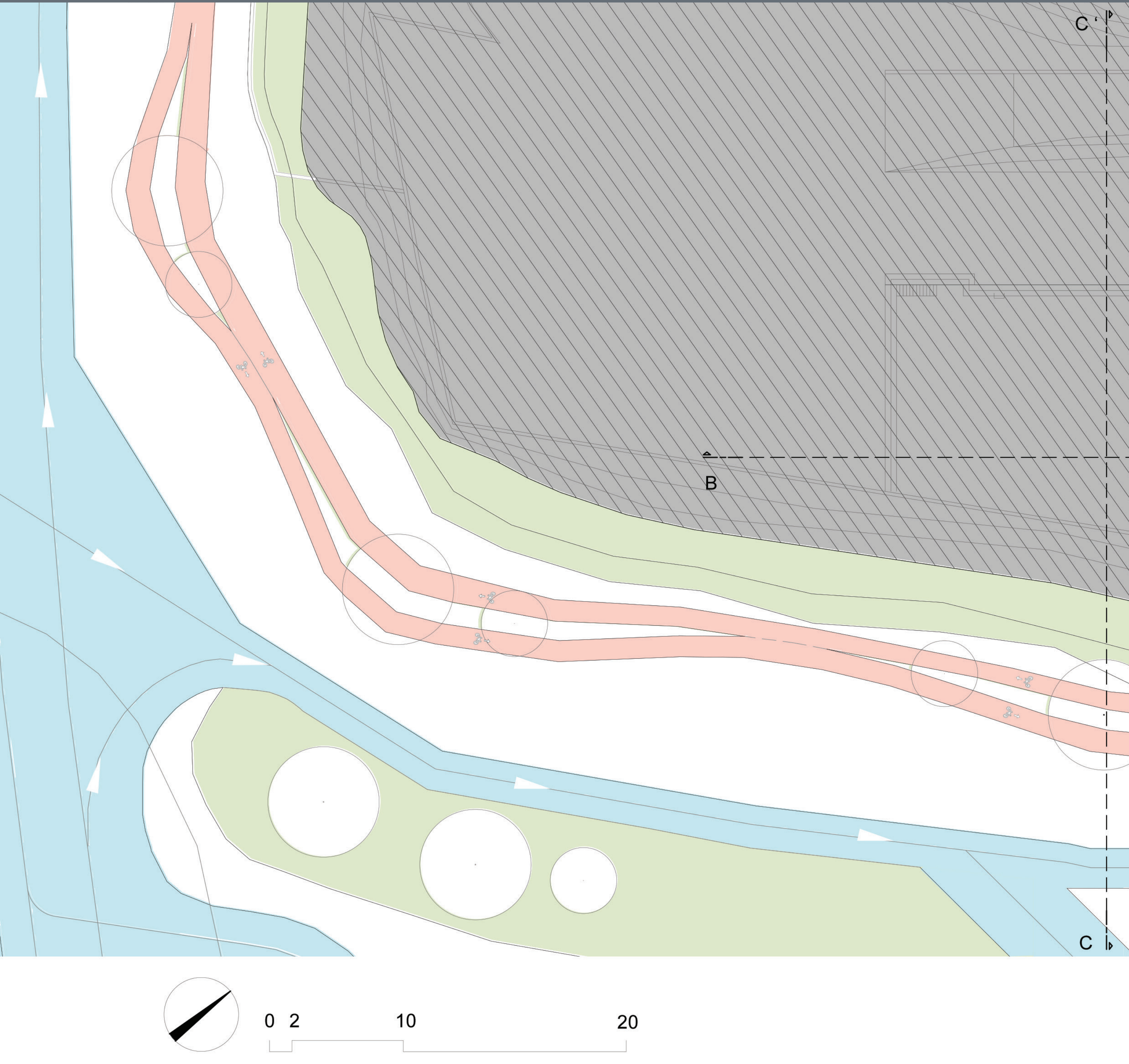
Como uma moeda de troca, este edifício é a oferta da cidade ao Porto pelas concessões generosamente partilhadas. Por essa razão, este hotel tem todos os elementos necessários para albergar exposições, conferências, workshop's e reuniões, funções fundamentais para o desenvolvimento do Porto.

Fig.58 Plantas e Alçado.

Fig.59 Implantação do Hotel

3. Proposta de Intervenção

A ideia de fazer um Hotel dedicado à entidade portuária de Sines advém da necessidade de ativar o potencial latente do Porto de Sines. Desta maneira, a solução arquitectónica enquadra-se num projeto estratégico que pretende definir em simultâneo, uma ideia de progresso e um compromisso formal com o lugar. Sendo o lugar da intervenção um espaço de contacto entre a cidade e o porto, o Hotel proposto estabelece uma transformação simbólica cujo principal objetivo é o de estimular a natureza produtiva da cidade.
Conciliando necessidades de espaços de empreendorismo, alojamento temporário e cultura, este edifício é dotado de uma complementaridade equilibrada entre funções de produção e lazer.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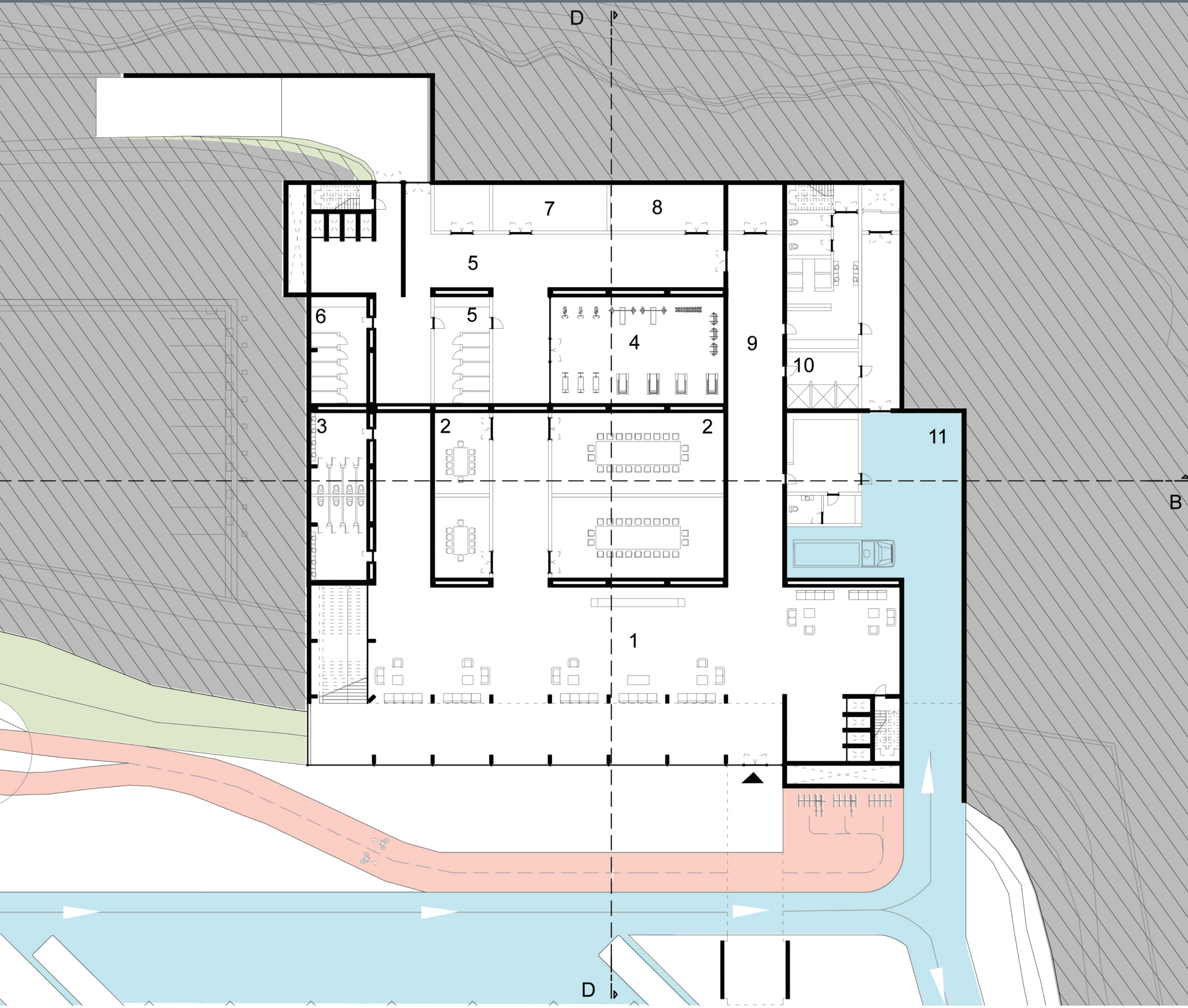
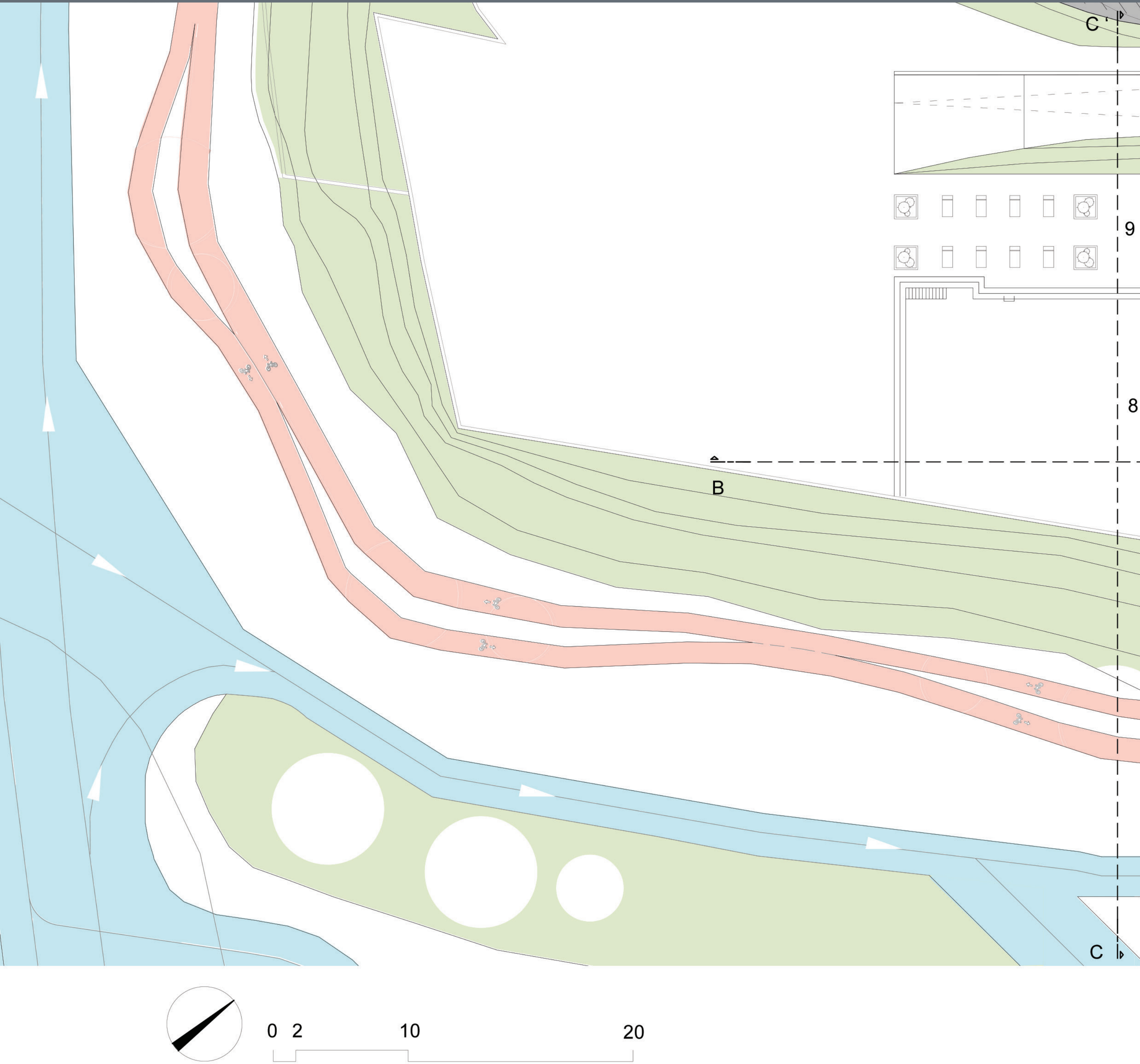


PLANTA PISO 0

1 - Átrio / Recepção | 2 - Espaço de Reuniões | 3 - Instalações Sanitárias | 4 - Ginásio | 5 - Balneários F |
6 - Balneários M | 7 - Sauna | 8 - Banho Turco | 9 - Acesso ao Ginásio | 10 - Economato | 11 - Cais de Descarga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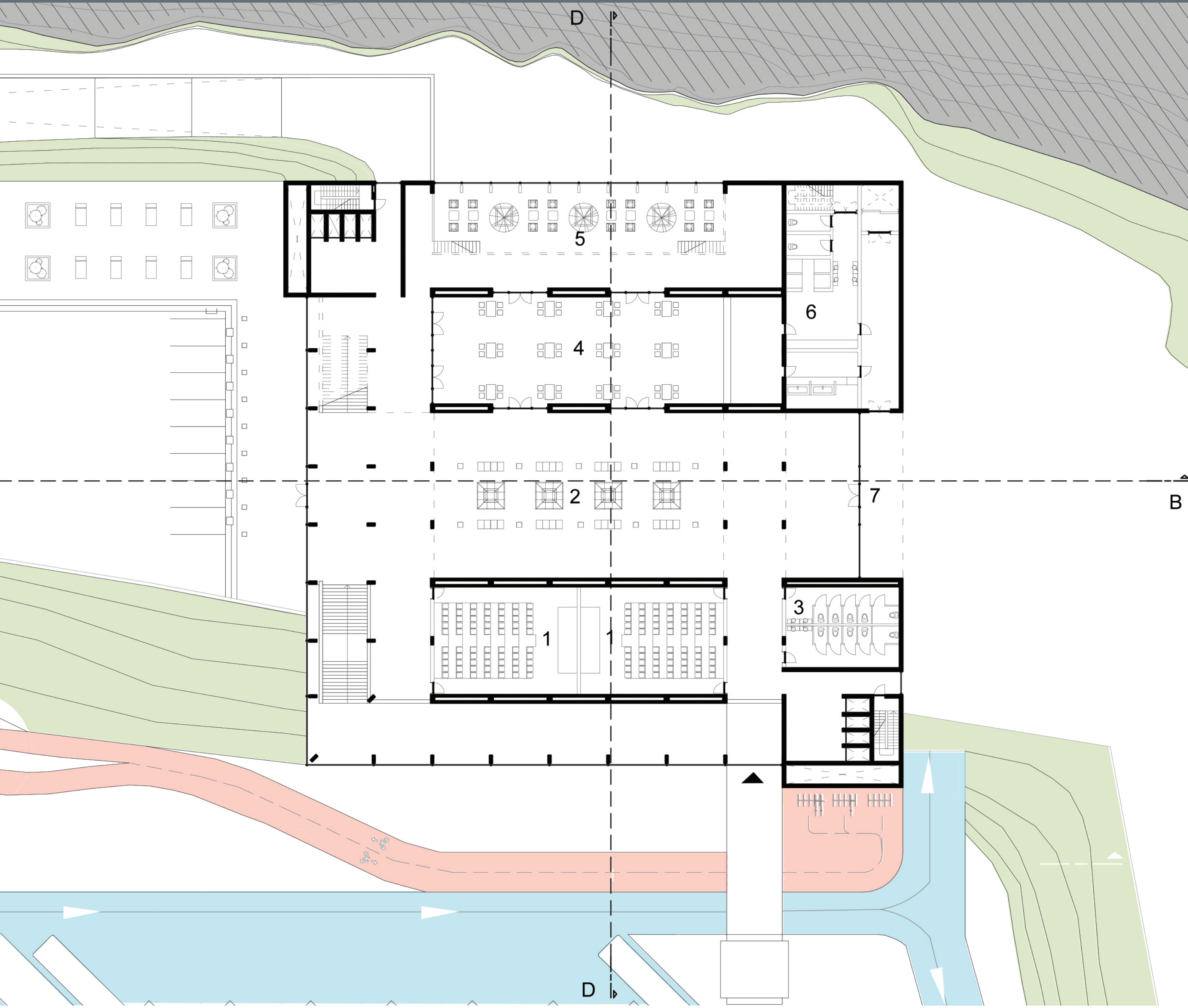
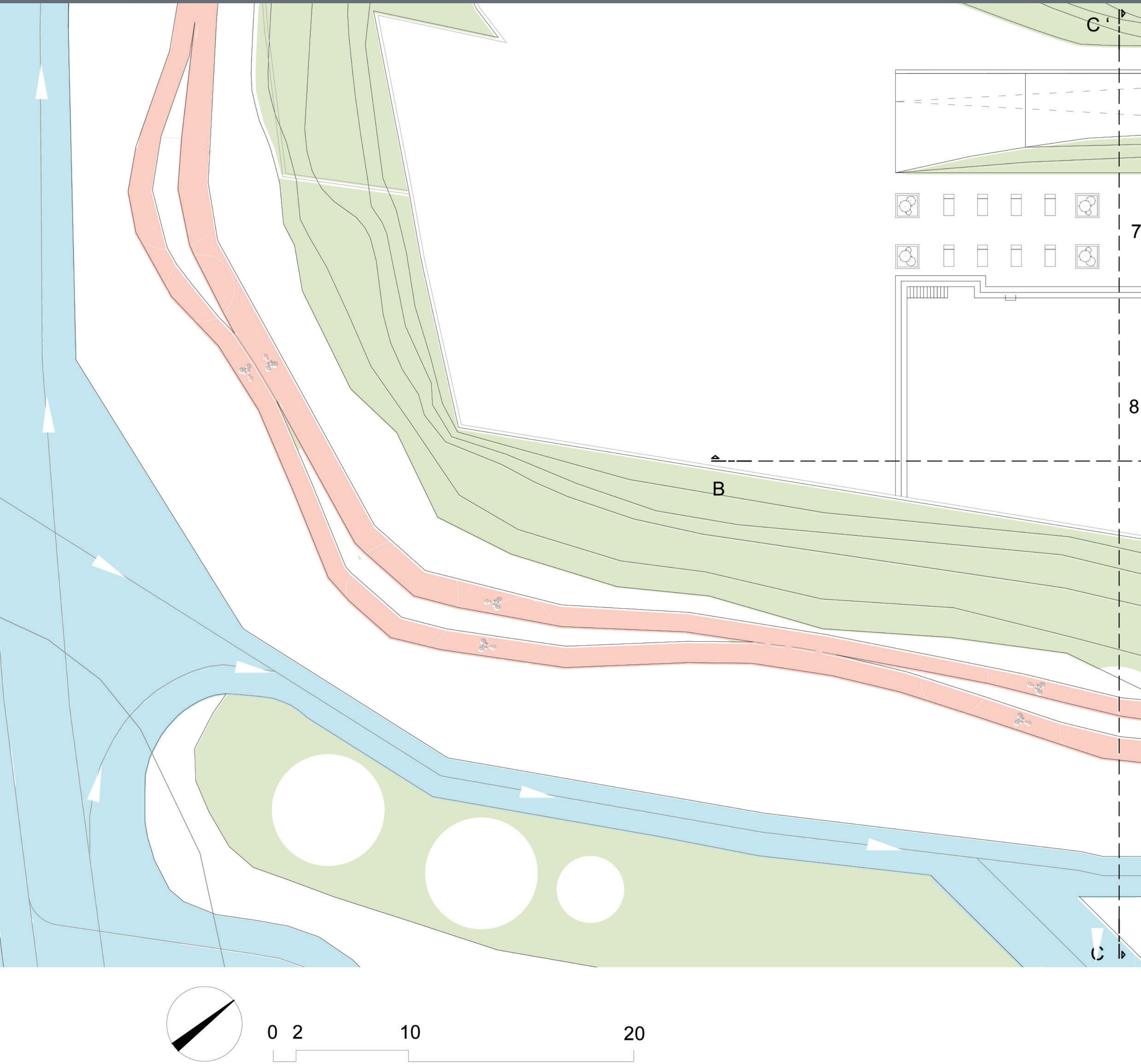


PLANTA PISO 1

1 - Auditório Polivalente | 2 - Zona Expositiva | 3 - Instalações Sanitárias | 4 - Bar | 5 - Esplanada Interior |
6 - Cozinha de Produção | 7 - Entrada Secundária | 8 - Piscina | 9 - Zona de Espreguiçadeiras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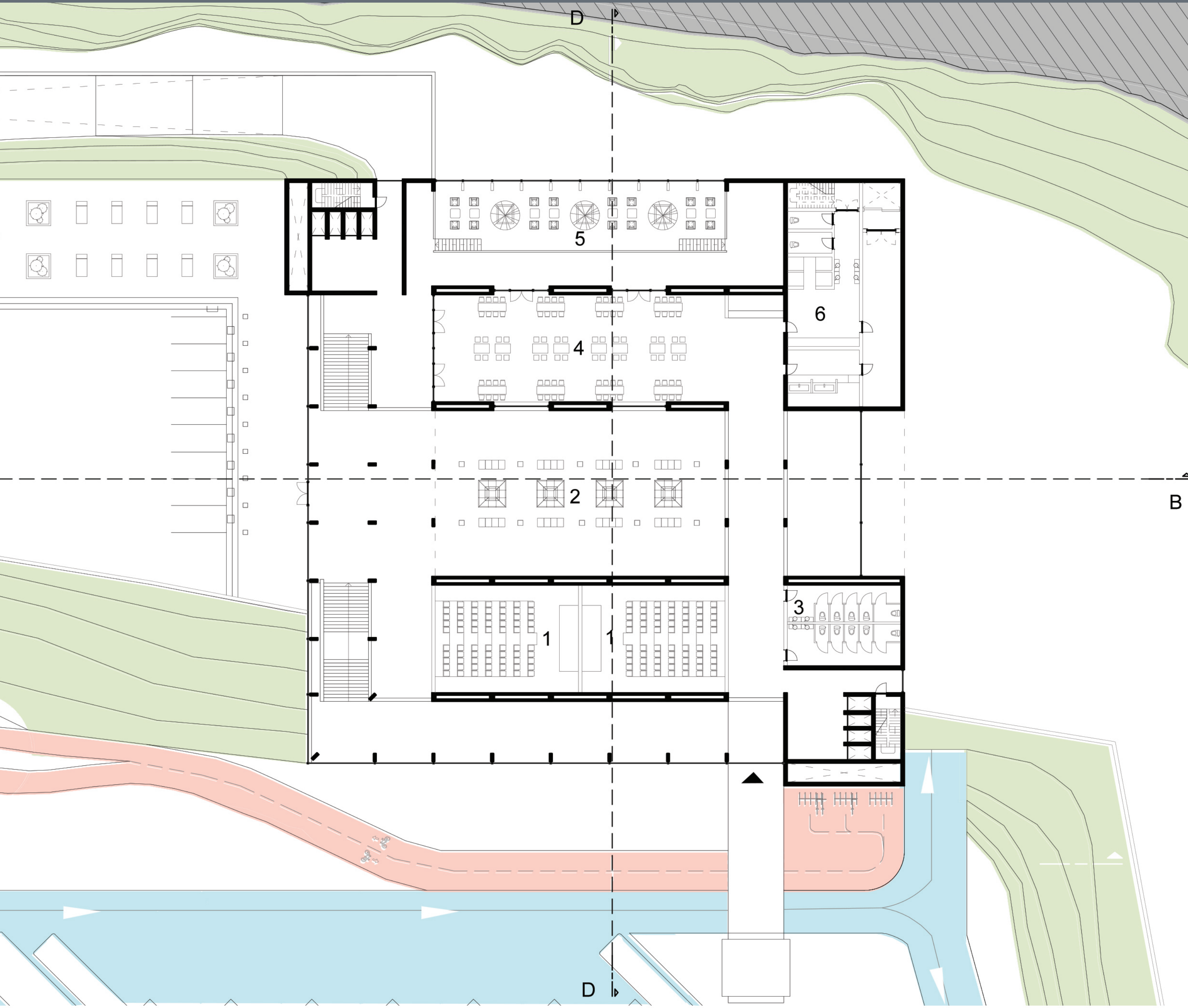
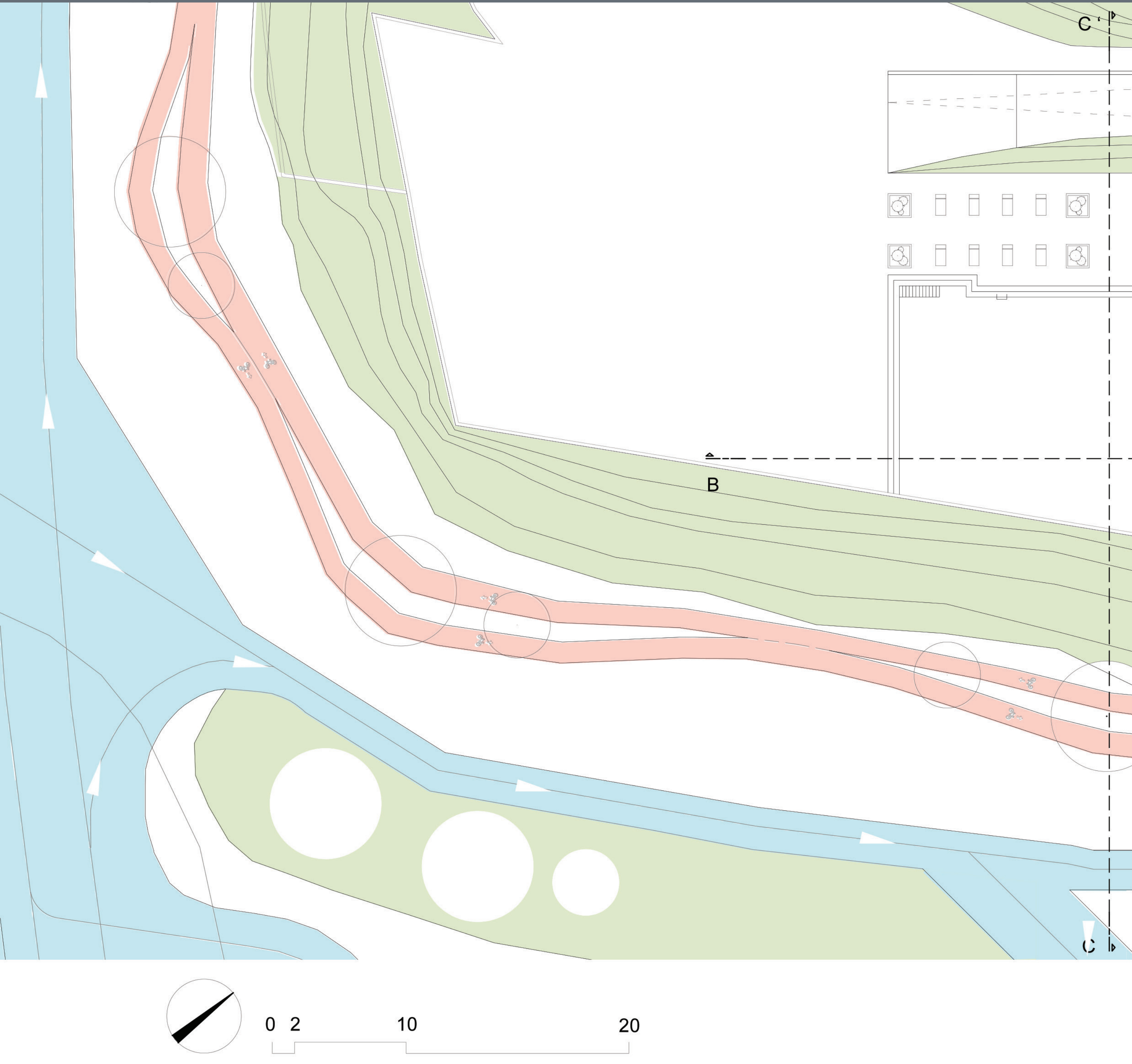


PLANTA PISO 2

1 - Auditório Polivalente | 2 - Zona Expositiva | 3 - Instalações Sanitárias | 4 - Restaurante | 5 - Esplanada Interior
6 - Cozinha de Produção | 7 - Zona de espreguiçadeiras | 8 - Piscina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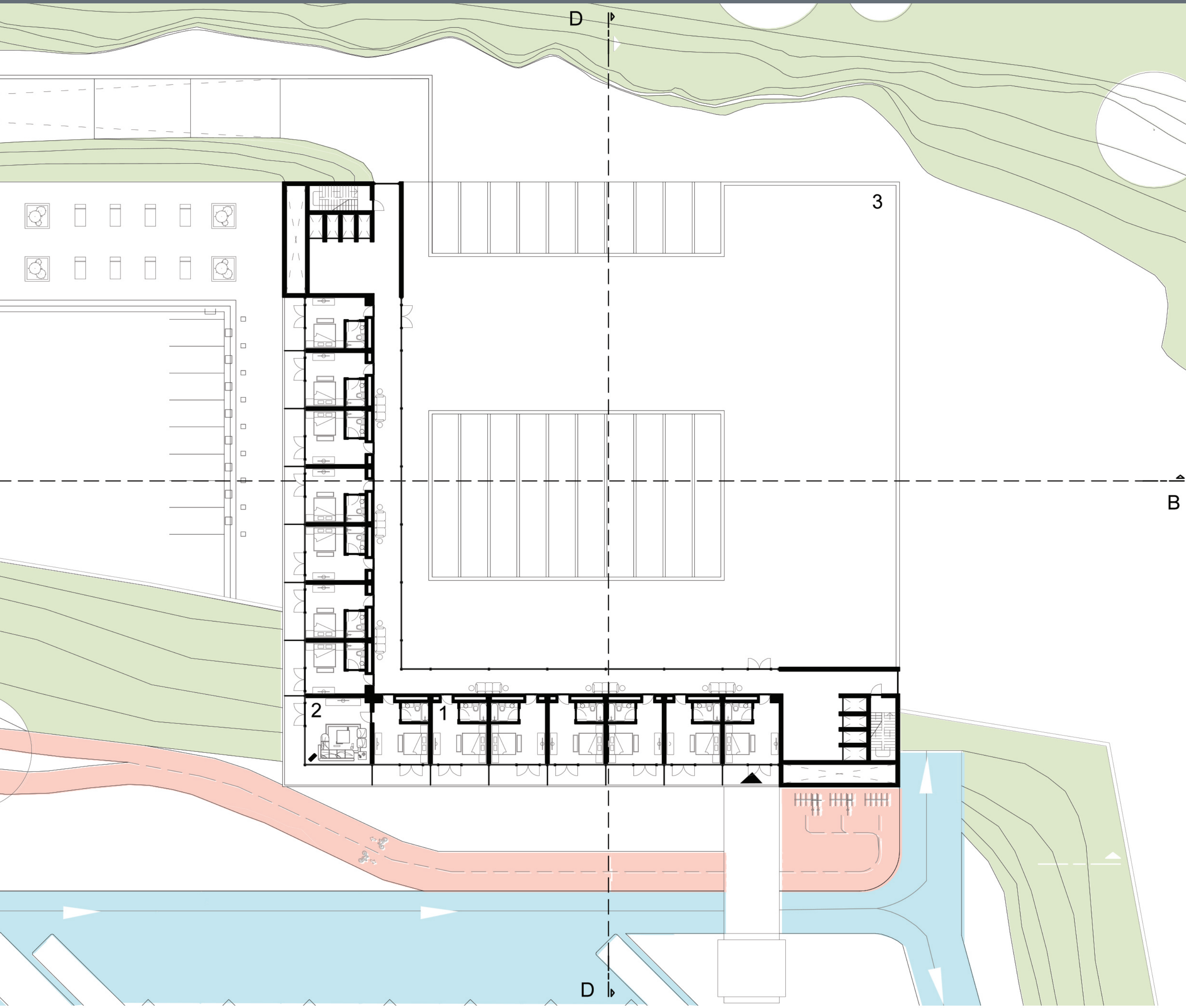
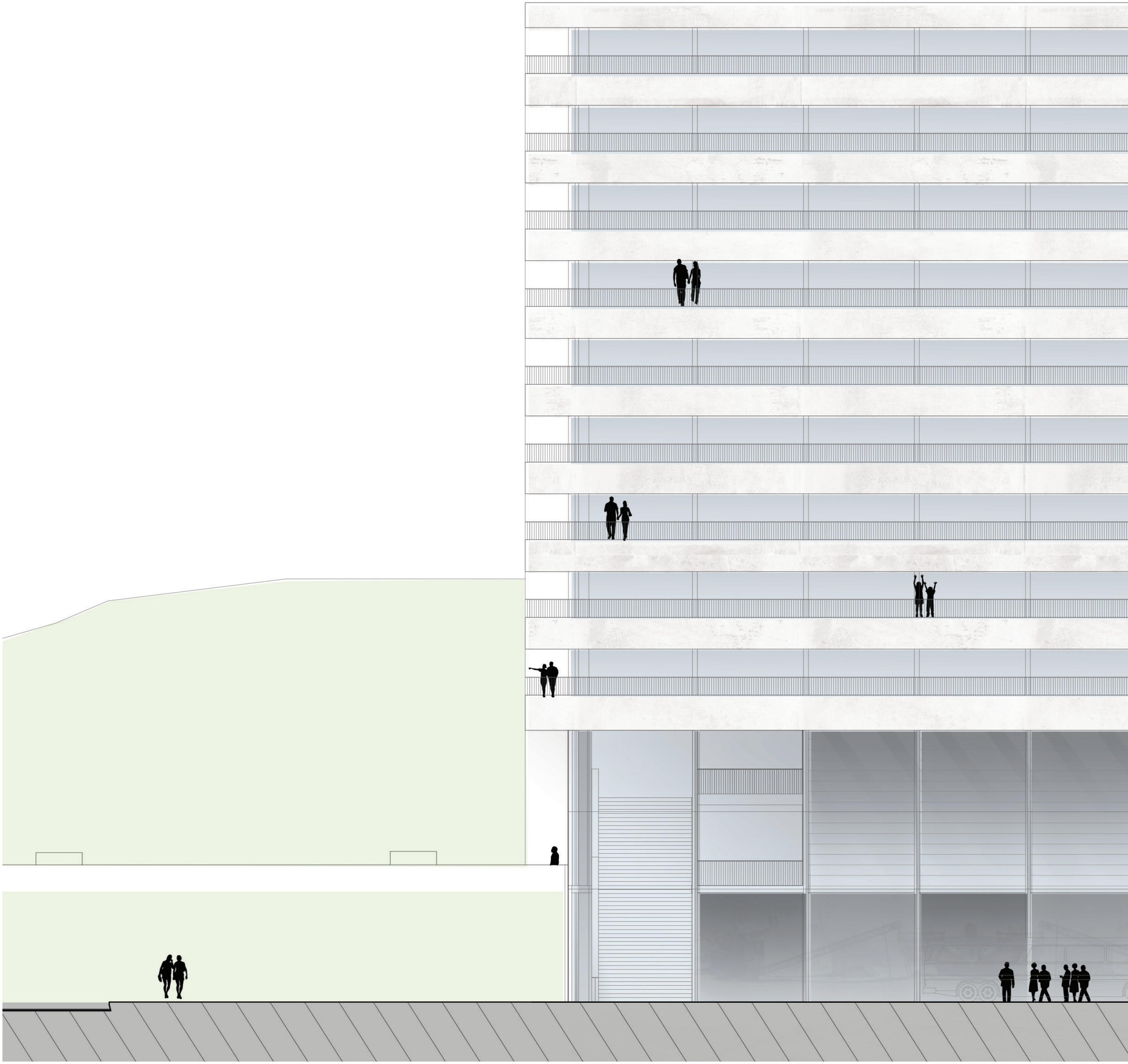


PLANTA PISO 3

1 - Suite | 2 - Suite Presidencial | 3 - Terraço



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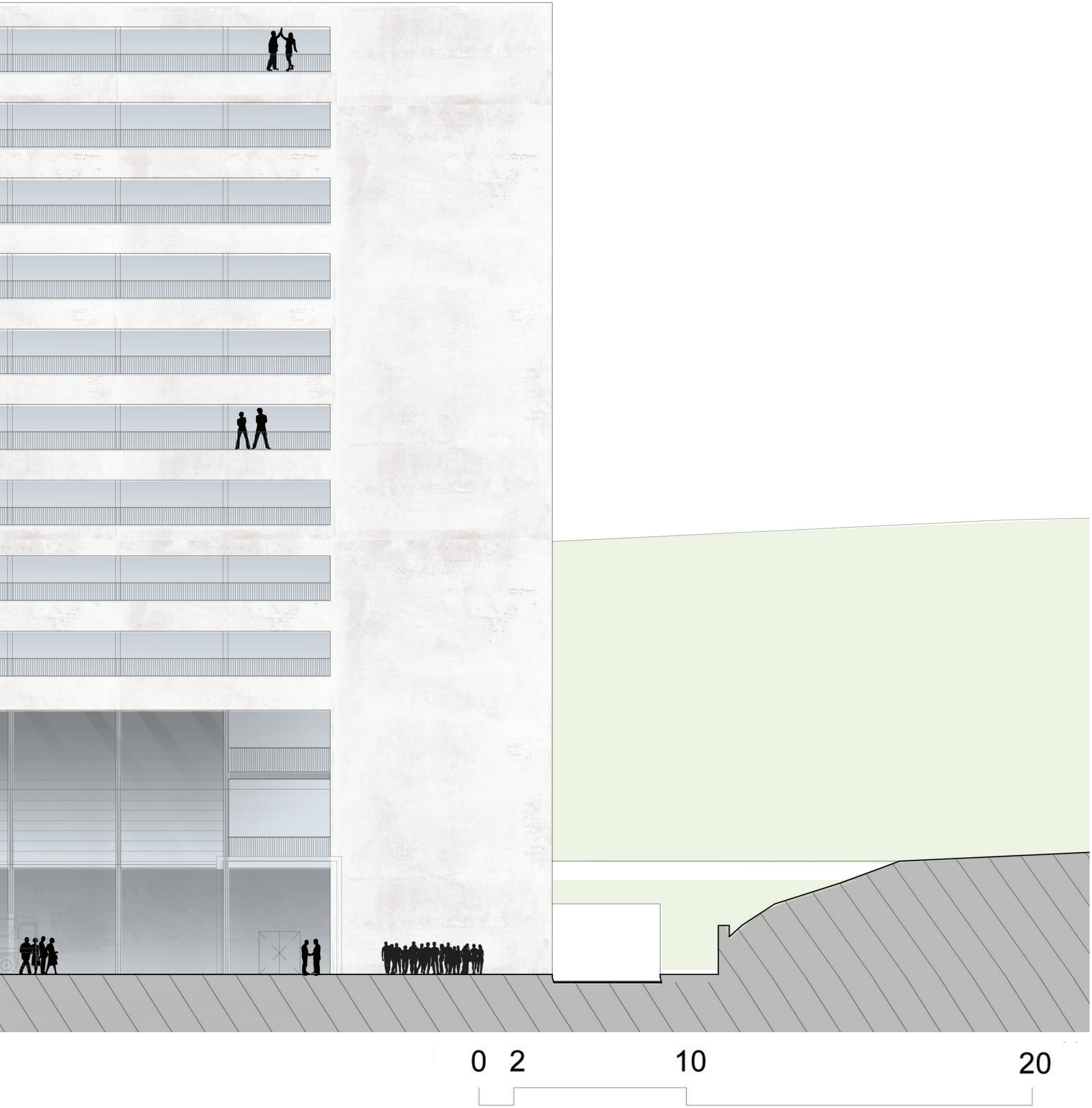
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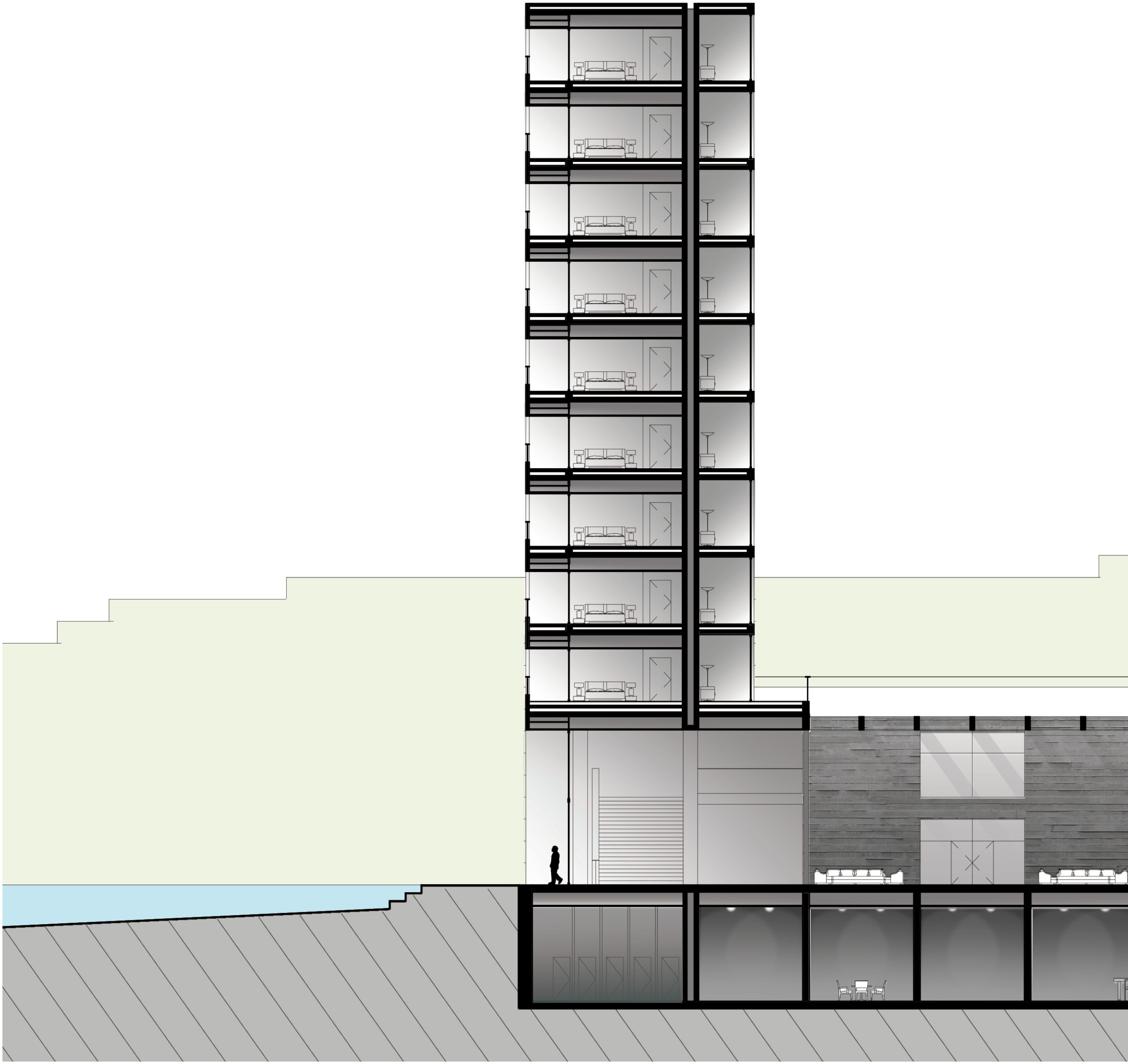

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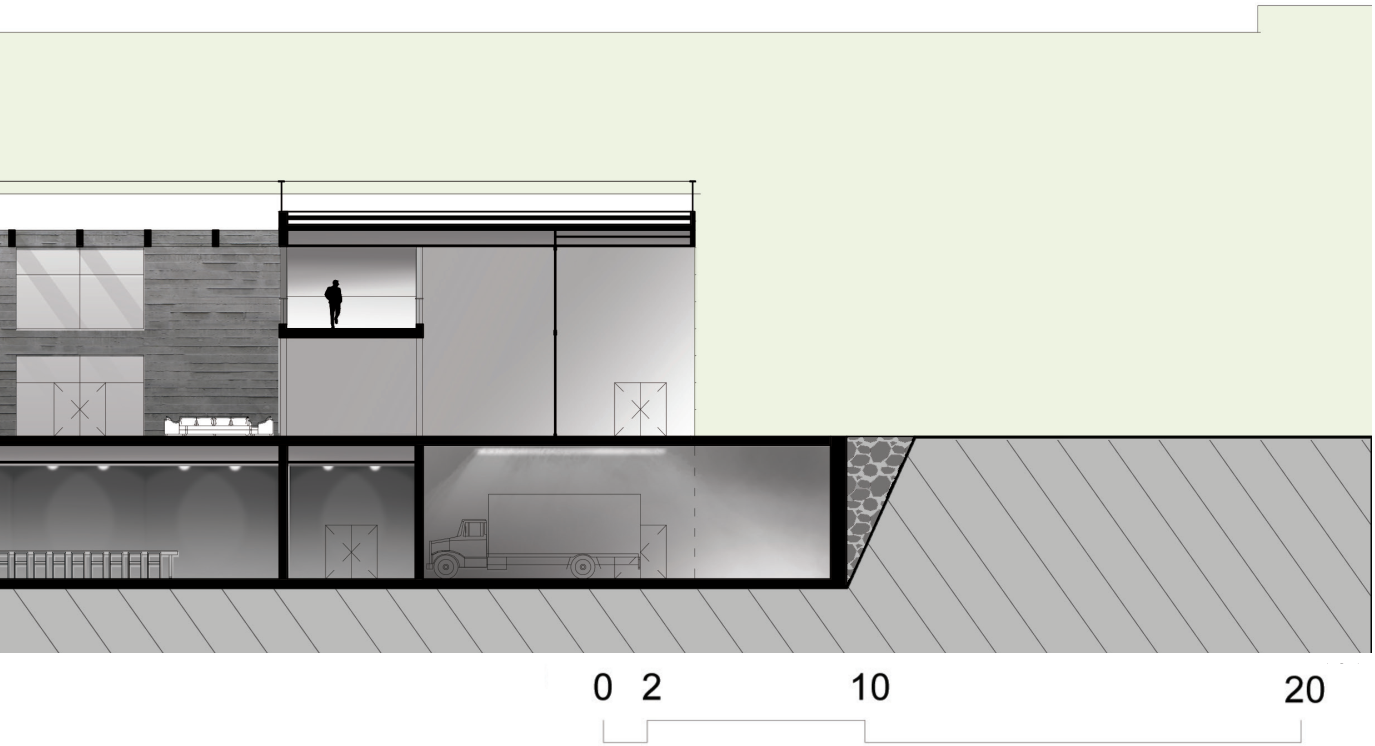
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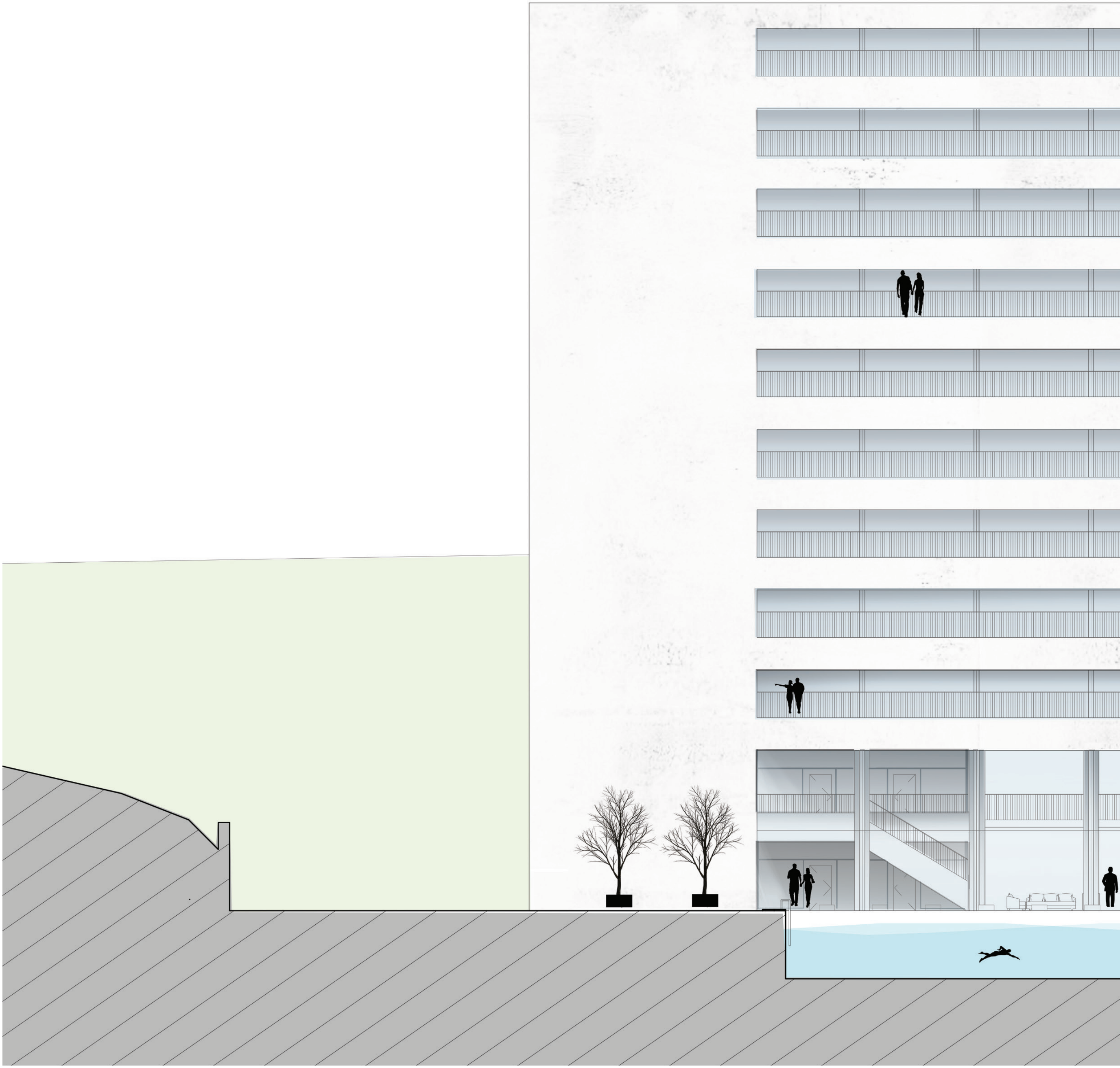

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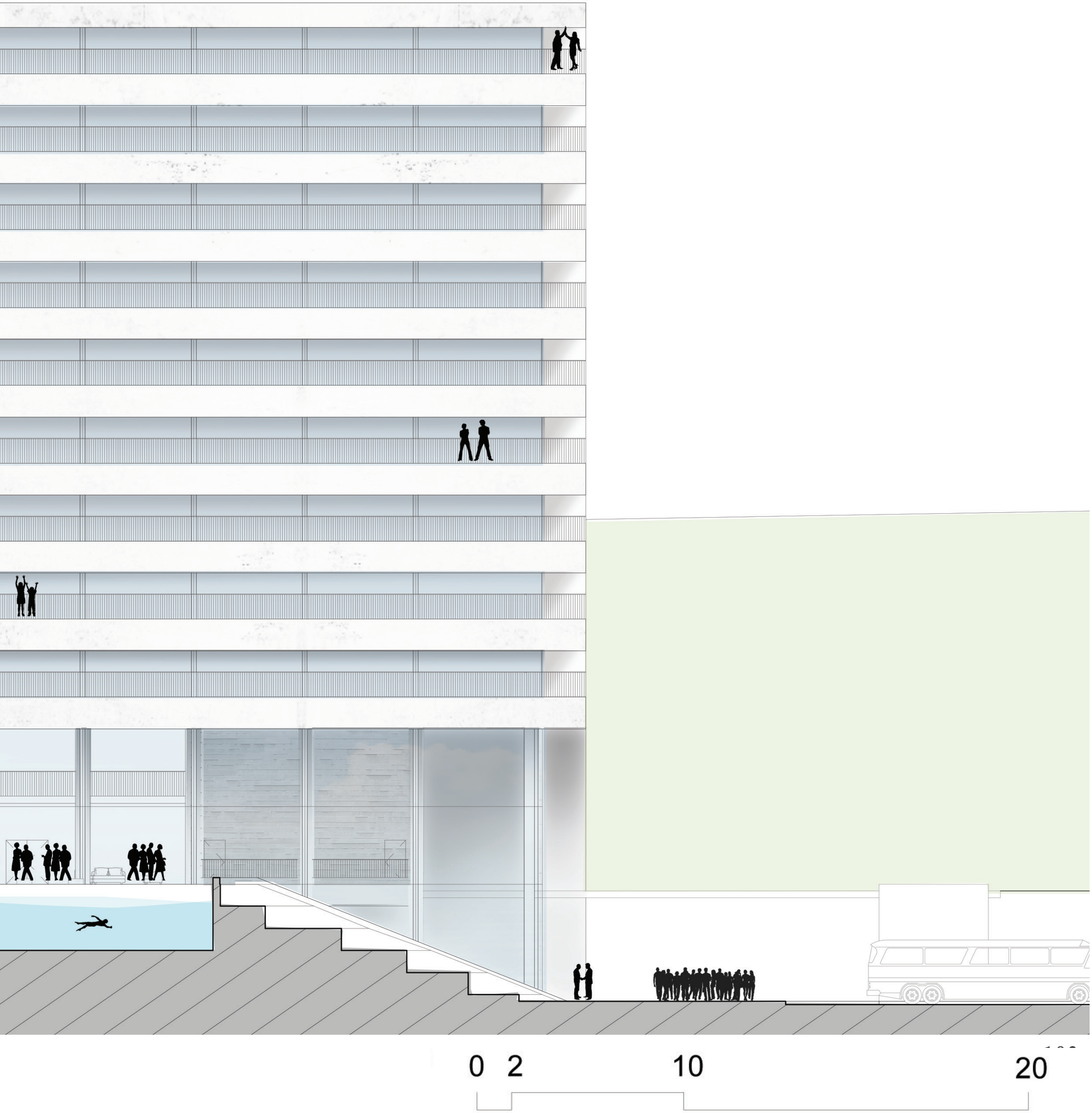
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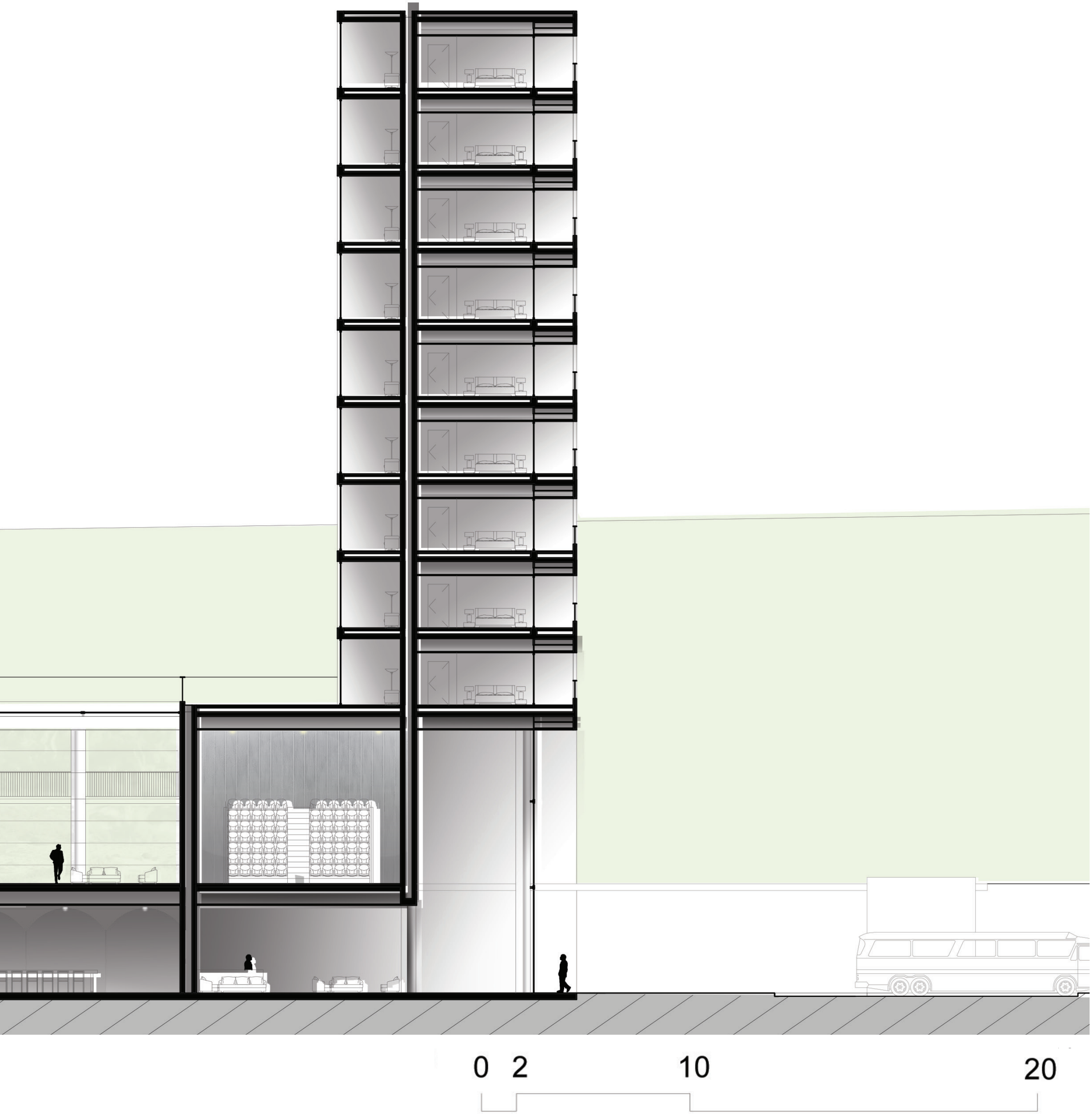
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Fig.60 Render do Alçado Poente

Fig.61 Render da Entrada

Fig.62 Render da Esplanada Interior

Fig.63 Render do Zona Expositiva

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ANEXOS

ISCTE-IUL
Departamento de Arquitectura e Urbanismo Mestrado Integrado em Arquitectura PROJECTO FINAL DE ARQUITECTURA 5aano, ano lectivo 2015/2016
Docente: Pedro Botelho

1- Os exercícios da UC de Projecto Final de Arquitectura do MIA no ano lectivo 2015/2016 serão desenvolvidos no âmbito do «Concurso Universidades», integrado na programação da Trienal de Arquitectura de Lisboa 2016, com o Tema «Sines-Industria e Estrutura Portuária».
É a oportunidade de trabalhar, em simultâneo com a maior parte das Escolas de Arquitectura do país, num dos Temas centrais da Estratégia de Desenvolvimento para Portugal dos últimos cinquenta anos (consultar a documentação enviada pela Trienal).

2-Pretende-se que os alunos desenvolvam simultaneamente trabalhos a várias escalas de concepção e projecto, explorando as múltiplas articulações possíveis desde a escala do território às do projecto de Arquitectura dos edifícios e vice-versa.

Pretende-se que os alunos desenvolvam o seu trabalho com base no entendimento do lugar e do contexto, dos seus problemas/potencialidades, nas diversas estruturas naturais, sociais e construídas.
Trata-se de encontrar uma estratégia de intervenção em que a definição do Espaço Público edificado e não edificado cumpra a sua função eminentemente estruturante do território. Trabalhar e investigar os programas para os edifícios e para o espaço público que melhor cumpram os objectivos de requalificação/regeneração do território em estudo. Seleccionar os locais a intervencionar com exactidão e rigor, integrando os valores patrimoniais existentes na estratégia geral de intervenção.

Pretende-se que os alunos desenvolvam em grupo uma leitura crítica do território proposto fundamentada no estudo da sua evolução/desenvolvimento ao longo do tempo. Este estudo permitirá a compreensão e a representação deste nas suas três principais componentes:

a) Espaços não ocupados por construção (vazios, verde, água, etc...).
b) Redes de distribuição de fluxos (vias férreas, de trânsito automóvel, pedonais etc...)
c) Massas de construção (corrente, industrial, comercial etc...)
Deverá ser dada especial atenção às grandes transformações operadas na paisagem natural e construída entre os períodos anterior e posterior à cocretização de todas as infra-estruturas portuárias/industriais e sobretudo às profundas alterações de escala daí resultantes.

Pretende-se que a partir da compreensão geral do território os estudos sejam aprofundados com o desenvolvimento de uma estratégia individual ou de grupo, para a reabilitação do Núcleo Urbano, e da Arriba e zona ribeirinha que o limitam a SW, desde o Cabo de Sines até à Pedreira.

Deverá ser dada especial atenção; aos percursos que vão desde a Casa Emmérico Nunes à Casa Pidwell e ao seu possível prolongamento até à Pedreira, à marginal desde a Antiga Calheta ao Café do Clube Naval e à Arriba com as suas rampas, escadas, elevador e coberto vegetal.

3- Ao longo do ano serão desenvolvidos três exercícios:

A-Leitura crítica do território proposto
Trabalho de grupo, caderno A2 com desenhos e texto dos momentos mais significativos do crescimento identificando os principais problemas/potencialidades das estruturas naturais e construídas e do seu funcionamento.
Entrega e discussão dos trabalhos na semana de 16 a 20 de Novembro

B- Estratégia de Requalificação do núcleo urbano e áreas ribeirinhas confinantes
Trabalho individual ou de grupo, caderno A3 com desenhos texto e maqueta.
Entrega e discussão dos trabalhos na semana de 14 a 18 de Dezembro

Os programas dos edifícios (reabilitação/reconversão e/ou construção nova) serão prioritariamente para Turismo/lazer/negócio ou Ensino/investigação e serão apresentados e discutidos em Janeiro de 2016. Para o desenvolvimento de qualquer projecto de reabilitação/reconversão de edifícios é indispensável garantir o acesso ao seu interior mesmo nos casos em que o levantamento já existe.

C- Projecto para o(s) edifício(s) e espaço(s) público(s) definido(s) em B
Trabalho individual, plantas cortes e alçados, memória descritiva, modelo 3D, maquetas com as seguintes fazes:

-Programa Base (deverá proporcionar a compreensão clara das soluções) -Entrega e discussão dos trabalhos na sema na de 1 a 5 de Fevereiro

-Estudo Prévio (deverá proporcionar a compreensão clara das soluções e a definição geral dos processos de construção)

-Entrega e discussão dos trabalhos na semana 14 a 18 de Março

-Projecto Base (deverá proporcionar a compreensão clara das soluções, a definição geral dos processos construtivos e o modo da sua execução)

-A selecção dos trabalhos para a Trienal será feita na semana de 25 a29 de Abril
-Projecto Final (deverá proporcionar a compreensão clara das soluções, a definição geral dos processos construtivos e o modo da sua execução com plantas e cortes construtivos)

--Entrega até ao final de Junho ou Julho

4-A avaliação de PFA será feita em júri de acordo com o estabelecido no artigo22o do DL 115/2013, no Regulamento Específico de Avaliação de Conhecimentos e Competências da ISTA e nas Normas Orientadoras para a Dissertação ou Trabalho de Projecto do 2o ciclo /Bolonha.

A apreciação dos trabalhos será feita de modo contínuo e incide sobre os trabalhos desenvolvidos pelos alunos e a sua participação efectiva tanto nos trabalhos de grupo como individuais. Será dada especial atenção à regularidade da presença dos alunos nas aulas e à interacção com o docente.

II. VERTENTE TEÓRICA

Resumo

Hoje em dia é cada vez mais importante ter um bom desempenho ambiental em edifícios e as paredes são parte fundamental deste processo. Devido á capacidade que as paredes têm de regular o consumo energético dos edifícios, escolher o material correto é fundamental para alcançar um bom desempenho ambiental. Esta é uma estratégia eficaz mas por vezes mas por vezes implica prejudicar o desempenho térmico da parede. Idealmente, o objetivo é ter um material que funcione tão bem como o betão mas com um melhor desempenho ambiental. A redescoberta recente da madeira trouxe nova esperança a este assunto por representar como alternativa competitiva ao betão, muito superior no plano ambiental. Na tentativa de perceber como é que o material se comporta exatamente, esta investigação propôs examinar como um conjunto de paredes em madeira se comporta em termos do seu desempenho térmico e ambiental. Para por as coisas em perspectiva estas paredes foram depois comparadas com soluções correntes e conclusões foram retiradas usando este método. Com este propósito, uma biblioteca simples foi criada, avaliada e comparada fazendo uso de folhas de cálculo simples, que se revelaram uma maneira bastante intuitiva de incorporar valores ambientais nas várias composições. Os resultados demonstram que as paredes em madeira funcionam bem em ambientes frios, mas não tão bem em ambientes quentes.

Palavras-chave: Desempenho Térmico, madeira, paredes exteriores

Abstract

Nowadays, it's increasingly important to have good environmental performance in buildings and walls have an important role in this process. Due to the capability of walls to regulate the building's energy usage, choosing the right materials is key to achieve a good environmental performance. That can be achieved by choosing a less pollutant material for walls, but sometimes that comes with a cost in performance. Ideally the goal here is to have one core material that performs as good as concrete but has a greater environmental value.
This idea has received renewed attention due to the recent rediscovery of timber as a competitive alternative to concrete, far greater in environmental performance. Intending to understand how exactly the material performs this research was conducted and aimed at examining how a set of timber walls behave in terms of their thermal and environmental performance.
To put things in perspective these walls were then compared with more common wall solutions and conclusions were drawn through this method. For this purpose, a simple yet accurate library of CLT external wall assemblies was created, evaluated and compared making use of simple calculation sheets which were found to be a very intuitive way of embedding environmental indicators in the different assemblies. Results show that timber walls perform well in cold climates but are not as good in hot climates.

Keywords: Thermal Performance, Cross Laminated Timber (CLT), external walls.

Índex

ILUSTRATION INDEX

i. Figures

i. Tables

List of Abbreviations and Acronyms

CLT – Cross-Laminated Timber

EWP's – Engineered Wood Products

LCA – Life Cycle Assessment

U – Heat Transfer Coefficient

EEs – Embodied Energy

ECs – Embodied Carbon

Mtsu – Net Superficial Mass

EPD – Environmental Product Declaration

1.1 Framework
1.2. Scope and Motivation
1.3. Methodology Approach

1.INTRODUCTION

1.1 Framework

Today buildings account for the use of 40% of all raw materials extracted by developed countries and generate 45-65% of the waste produced. Energy and water used in production are also important and account for 70% and 12% respectively [1]. These numbers give buildings a fundamental role in the mitigation of hazardous environmental impacts all throughout developed and undeveloped countries. Even though low operational energy[1] is the best-known procedure to reduce overall energy waste in buildings, numerous studies suggest that, as operational energy tends to be reduced, embodied energy[2] will increase its significance over time [2]. Michael Green addressed this issue in his study “The case of Tall Wood”, and found out that wood is the most promising alternative to energy intensive materials in buildings, as it can be used in almost all components of a building. [3] Cross-Laminated Timber (CLT) for instance can be combined with new structural approaches to behave significantly different from lightwood buildings, in their ability to provide safe mid-rise (6-12 stories) and tall buildings (+/- 30 stories). This is particularly important in cities like Berlin, Copenhagen, Istanbul, London, Paris, Shanghai, Stockholm or even Washington DC where demand for tall buildings is increasing. In the current model, this growth represents an unsustainable threat because of the chaotic development of urbanization and its inability to build affordable and sustainable living space. However, if a new model is implanted, this growth poses great opportunity for cities to be transformed towards more compact urban infill and by doing so improving mobility and land consumption. This is why cross-laminated timber systems have such an important role to play in the development of better models of urban growth. Recognizing this key role of CLT in the development of sustainable, livable

1 Energy used heating, cooling and sustaining a building throw the life cicle.

2 Energy embedded in the materials.

awareness about the product. Secondly, this research is aimed at examining what's the optimal assembly for a wall made in CLT. Regarding external walls, there is usually a conflict between the desired material and the best environmental solution – due to lack of reliable data about the environmental impact of certain products – and even though wood is well recognized to have a good environmental performance – and by association CLT panels – these savings are not fully understood and generally not accounted for in the design phase. As the environmental argument is frequently used to point out that CLT should replace concrete and steel, this research intends to solidify that argument by measuring just how good CLT is in each environment. Additionally, but not less important, is to understand how CLT walls behave in terms of their thermal performance, as the indoor environment is greatly influenced by the thermal conductivity and inertia provided by the building envelope. To raise awareness about CLT and because most developers feel they have no benchmark when planning to do CLT buildings, a blog was created to provide support. It stores all the resources used during this research, aiming to facilitate access to articles, projects and other useful resources regarding cross-laminated timber .[3]

3 http://http.crosslaminatedtimber.tumblr.com

1.2 Scope and Motivation

Cross-Laminated Timber (CLT) has been around since the 90's and several examples of CLT construction can be found all across Europe [4]. It is an outstanding wood-based product that combines great mechanical properties with quality seamless finishing's and low environmental impact. Even though it is not a new material, recently the product has seen a surge of popularity, by starting a race to build the tallest plyscraper [4] in the world. The problem is that the learning curve of an entirely new building system can be a bit challenging. All across the building industry, architects rely in technology to make the multidisciplinary task of erecting a building a little less daunting. For example, when decision makers need to choose the product that best suits their needs, a lot of different criteria need to be accounted for. This process benefits from having automatized and simplified tools because, as with any new technology, CLT acceptance in the market relies on the ability of the system to be used in such an extent that can at least match the previous one. Therefore, the tools used in this research can be useful to engage architects in sustainable construction.

The purpose of this dissertation is to show:

- The state-of-the-art of Cross-Laminated Timber Technology;
- The thermal and environmental performance of CLT external walls;
- That the use of simple calculation and analysis tools can be beneficial to embed environmental indicators in performance-based decisions.

4 A skyscraper made from wood

1.3 Methodology Approach

Primarily this research is focused on gathering information about CLT and putting together a resource that can provide guidance to academics and get them talking about high-rise wooden architecture. This is done by creating a blog that tracks CLT history, and makes sense of the 20 years the material has. As for the time of this research, CLT is still so unheard off that the architectural community doesn't even has a single terminology for the material. It floats between X-LAM, Massive Timber, Cross-Lam or Cross-Laminated Timber (CLT). Due to this, translation to Portuguese is currently inexistent. The second phase consisted of designing and choosing the walls to evaluate. After knowing the types of insulations and the thicknesses of CLT panels it was time to gather Environmental Performance Declarations (EPS) to use in prior calculation of the environmental and thermal performance of the walls. These were the criteria chosen. Having determined these criteria it is possible to then proceed and evaluate the performance of the walls, breaking down an inventory of all the materials used in each assembly. Assemblies were rated considering two different project scenarios, namely hot dry climates and cold climates. The best-rated solutions were then compared with heavyweight walls already assessed in previous work. [5] From this comparison, interesting conclusions can be attained and will be discussed at the end of the work.

1.1 Importance of choosing the right materials

1.2 Current methodologies for material selection

1.3 The role of external walls

1.4 The Case of Cross-Laminated Timber

2.STATE OF THE ART

2.1 Importance of choosing the right materials

Sustainability is one of the best fields in which companies can be competitive and innovate, creating business value. [6] Choosing the right materials is not only important as it is in fact an opportunity. While addressing environmental challenges, companies can reduce costs, generate new revenue and improve productivity. Recent efforts in renewable energy infrastructure made room for concepts like the Zero Energy Building (ZEB) to prosper, and led the Directive on the Energy Performance of Buildings of the European Parliament and of the Council of 19 May 2010 (EPBD) to establish the target of near zero energy buildings, for all public buildings at 2018 and for all new buildings at 2020 [7]. As a result, many countries are starting to be complacent with these new challenges and it's important that companies learn to cope with the idea of more efficient buildings. Due to prospects on future low operational impacts, attention will most probably build up towards the environmental impact of building materials (raw materials extraction, manufacturing process and delivery to the construction site) which, alone, can account for 2-38% of the overall energy consumed in a 50-years lifespan for conventional buildings and 9-46% in low energy consumption buildings [8]. These indicators substantiate the key role that green materials have in achieving a truly sustainable building. Thinking long term about the environment is a main concern that needs to be accounted into business planning if a company wants to reduce risks in the years ahead and create opportunities.

2.2 Current methodologies for material selection

A wide range of tools does exist to help individuals engage on environmental issues. Some are widely used in the industry and allow a standardized manner of communicating environmental data. The life-cycle analysis (LCA) [9], gave the market a common environmental language and gained broad acceptance throughout the world in such an extent that the information it provides will likely be a mandatory requirement for products to have in the near future. Through this data, the embodied carbon of building materials can be calculated in two different ways. One is by calculating the carbon data in an area-based approach. This might be a good way to engage in sustainability, and can originate generic values that can then be optimized using reference data from institutions like the Green Guide and French EPD. A more rigorous alternative is breaking down an inventory of all the materials used and proceed to evaluate their environmental footprint taking advantage of intelligence provided by the Inventory of Carbon and Energy (ICE) database [10] as well as the LCA databases [10]. In this sense, calculating the embodied carbon of materials is not much different from calculating its cost and by incorporating such techniques, companies can get valuable insight about the materials they're using, gaining the possibility to choose more environmentally friendly alternatives to use instead. Although LCA assessment performs well evaluating the environmental impact of materials, it cannot yet be directly applied to buildings [11] and simplified tools are still needed to motivate planners about opportunities to innovate.

2.3 The role of external walls

If a single component of a building was to be regarded as important it would most likely be external walls. The requirements that need to be fulfilled by this component besides stiffness, stability and durability are unique and range from weather and heat transmission to sound impacts, fire safety and security.

Mostly, external walls are important to guarantee thermal comfort of occupants within the built environment. Achieving indoor thermal comfort means storing and distributing solar energy (heat) by absorbing it in the cold seasons and blocking it the warm ones, making use of natural ventilation and heating strategies. This concept is what's called passive solar design and makes use of external walls to perform accordingly [12].

Thermal comfort can also be viewed in economic terms and usually comes as beneficial when planned to lower environmental impact throughout the building operational phase. Nevertheless, thermal insulation can be viewed as an investment [13].

External walls are also the main component protecting the indoor environment from external impacts. By regulating the indoor quality and comfort, external walls impact energy consumption and the degradation of the environment. As the first line of defense and largest component of a building, external walls need to be designed with appropriate assessment tools and perform as a major regulator of several sustainable factors such as thermal and transmission processes.

The scheme of fig.1 supports in understanding the regulatory and protective functions of a building envelope, in which external walls play a significant role by protecting buildings against wind, vapor pressure, rain, pollution, and solar radiation [15].

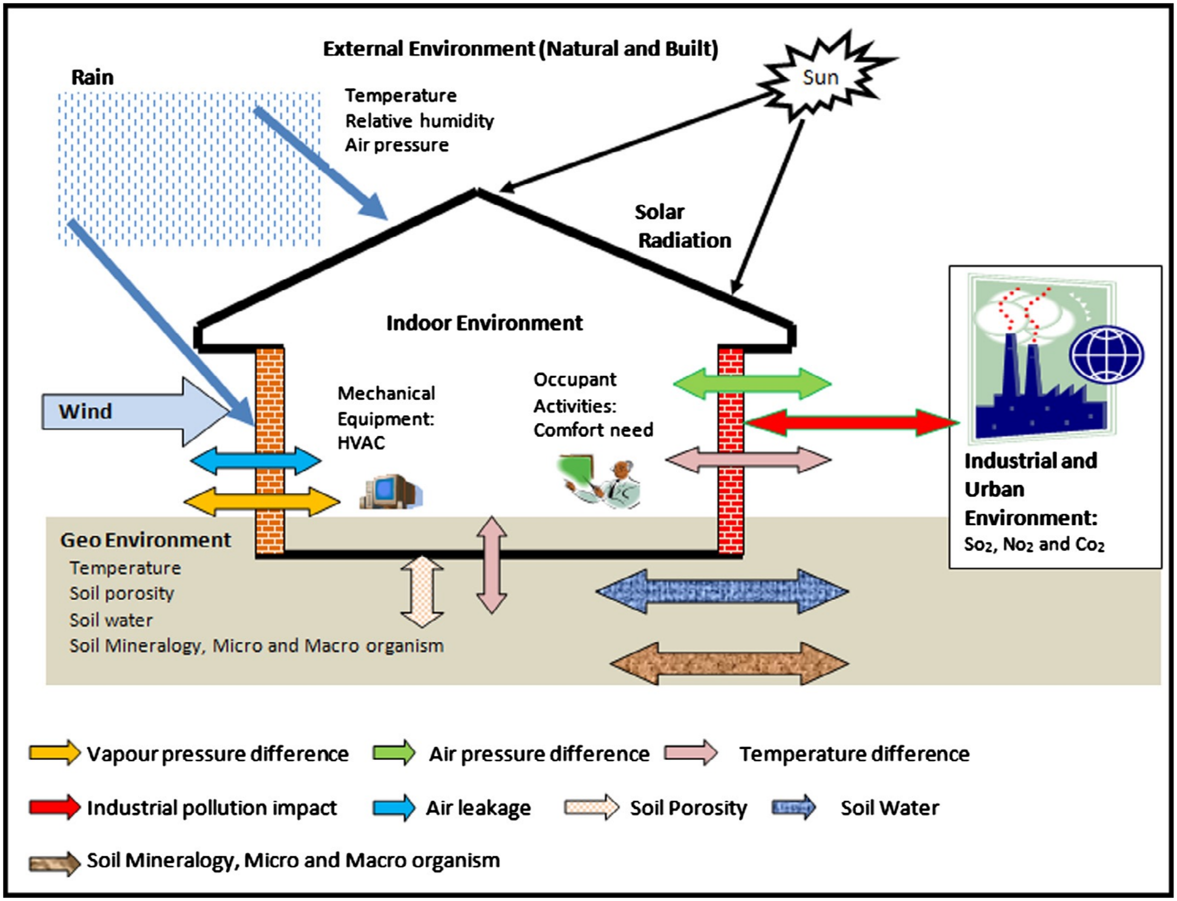


Fig.1 Environmental loads on building envelope [15]

2.3 The Case of Cross-Laminated Timber

Cross-Laminated Timber (fig.2) or CLT (also referred to as “X-Lam,” “Massive Timber” or “Cross-Lam”). Was developed in Europe in the early 1990s and it is an engineered wood-based product made of multiple layers of wood boards oriented perpendicular to the adjacent layers [15]. Other engineered wood products (EWPs) are already widely used in the built environment such as Oriented Strand Board (OSB), Medium Density Fiberboard (MDF) and Glued laminated timber (Glulam). Engineered woods such as the ones mentioned above are developed to achieve high strength performance, enhanced durability and consistency. By making use of wood grain, EWPs can be assembled with low-value and small-diameter trees, making good use of forest resources and striking deforestation [16].

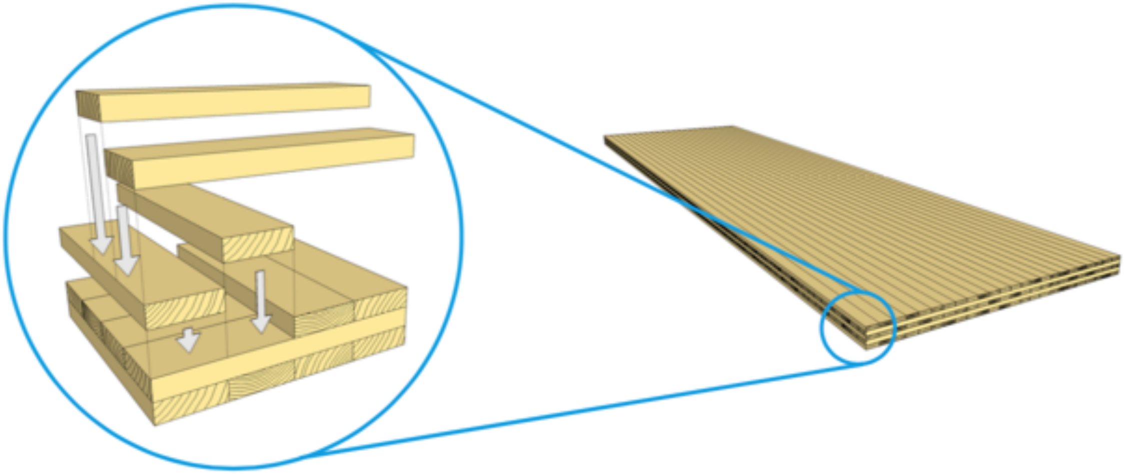


Fig.2 Detail of Cross-Laminated Timber Panel [17]

Since its appearance, CLT panels experienced rapid growth in Europe and have been used in a wide range of buildings with residential, educational and office purposes. While this product is well established in Europe, the work on the implementation of CLT products and systems has just begun in Canada and United States. It's considered particularly competitive in mid-rise and high-rise buildings, making it a viable product to promote the shift towards sustainable densification of urban and suburban centers in Canada and the USA [4]. As with any new material, several tests had to be done to ensure CLT met the established requirements. Some of these tests, are reviewed her and show that CLT satisfies most standards. It's also demonstrated that cross-laminated timber is very different from lightweight wood and that adopting this system brings several advantages to the built environment, such as: smaller foundations, smaller assembly costs, smaller maintenance costs, higher reusability and good fire performance.

Overall, CLT is known to have:

Sustainability:
- Reduced embodied carbon
- Minimal waste in production
- High energy efficiency

Performance:
- Disaster resilience
- Good fire resistance
- High performance acoustics
- Structural Flexibility

Efficiency:
- ~75% lighter than concrete
- Reduced construction time
- Precise Pre-fabrication

Global Production of CLT

Since the material was first introduced in the construction market, its production rose greatly reaching a global annual production close to 600,000m3 in 2014 (fig.3). To put things in perspective global production of concrete by this time was close to 3,500,000m3 [18]. This slow steady growth has nearly doubled its significance in 2016 as Finland, Latvia, Japan and the U.S. came on board. Most of this production is concentrated in central Europe (60% in Austria, 17% in Germany, and 3% in Switzerland). The largest supplier is Stora Enso, producing an annual average of 120,000m3 [19].

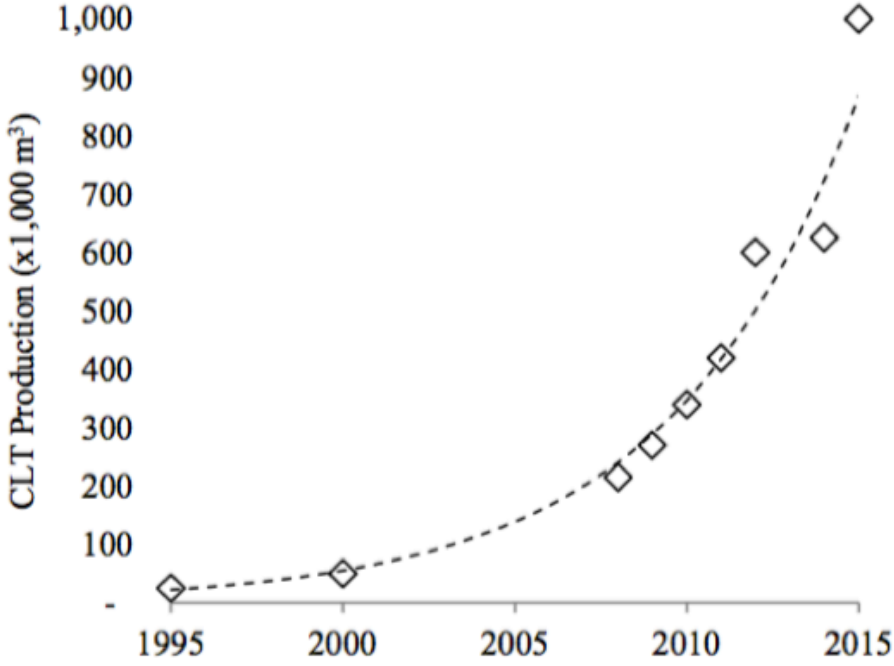


Fig.3 Global production of CLT 2015 [19]

CLT Researsh in Europe

Ignited by the Swiss government in the 90's to put sawmill by-products to use, modern CLT is the result of a joint effort between industry and academia to develop the product. The resulting material has been broadly accepted and by 2012 there were already over 100 CLT projects in Europe [20]. Just recently, CLT has seen an unprecedented growth by drawing attention from all over the globe. This renewed interest in the technology led several institutions in Europe to conduct new research about CLT (Table 1). Additional research is being carried out by a special working group within the COST Action framework to "collect, discuss, assess, harmonize and condense fragmented state-of-the-art concerning CLT with focus on testing and design. Among other subjects, this group is leading the incorporation of CLT into the European Standard and developing a European version of the CLT Handbook, expected to come out in 2018" [19].

Table 1 – Research institutions conducting research about CLT in 2015. [19]

Institution	Location	Reference
Institute of Timber Engineering and Wood Technology; Graz University of Technology	Graz, Austria	(Graz University of Technology 2015)
Vienna University of Technology	Vienna, Austria	(Vienna University of Technology 2015)
Institute for Timber Construction; Structures and Architecture; Department of Architecture, Wood and Civil Engineering (AHB); Bern University of Applied Sciences (BFH)	Biel, Switzerland	(Bern University of Applied Sciences 2015)
Institute of Structural Engineering, Swiss Federal Institute of Technology	Zurich, Switzerland	(ETH 2015)
Department of Engineering Structures; Swiss Federal Laboratories for Materials Science and Technology (EMPA)	Dübendorf, Switzerland	(Empa 2015)

Table 1 – Research institutions conducting research about CLT in 2015. *(cont.)*

Laboratory for timber construction (IBOIS); Swiss Federal Institute of Technology Lausanne (EPFL)	Lausanne, Switzerland	(EPFL 2015)
Department of Civil Engineering; Geo and Environmental Sciences; Karlsruhe Institute of Technology (KIT)	Karlsruhe, Germany	(KIT 2015)
Chair of Timber Structures and Building Construction; Technical University Munich	Munich, Germany	(TUM 2015)
Department of Structural and Mechanical Engineering; University of Trento	Trento, Italy	(University of Trento 2015)
CNR IVALSA Trees and Timber Institute; National Research Council	Trento/Florence, Italy	(CNR-IVALSA 2015)
Department of Architecture; Design and Urban Planning; University of Sassari	Sassari, Italy	(University of Sassari 2015)
Faculty of Engineering; LTH; Lund University	Lund, Sweden	(Lund University 2015)
Norwegian Institute of Wood Technology	Oslo, Norway	(Norsk Treteknisk Institutt 2015)
Department of Architecture and Civil Engineering; University of Bath	Bath, UK	(University of Bath 2015)
Contemporary Building Design - CBD	Ljubljana, Slovenia	(CBD 2015)
Department of Architecture and Design, Politecnico di Torino	Torino, Italy	(Politecnico di Torino 2015)

* Not claimed to be exhaustive. Based on Internet search, peer-reviewed journals, and consultations with experts.

Awareness of CLT

Two interesting studies have been scanning the industry about the awareness and willingness to adopt Cross-Laminated Timber by the architecture community. The results are quite surprising knowing that CLT is around for over 20 years now. It was found that the awareness is “low” or “very low” for construction managers, contractors, and owners/initiators within the building industry. Controversially, architects and engineers are rated with “high” or “very high” level of awareness. Reasons undermining the adoption of CLT include: compatibility with building code, availability of technical information, misperceptions about wood or CLT and cost. Additionally, availability in the market and volume of wood required for CLT construction is also a concern [19]. If contrasted with the U.S. [21], concerns are similar for cost and lack of technical information but differ greatly regarding the availability of CLT, which is not surprising taking into account that there is only one manufacturer in the U.S. producing CLT panels (SmartLam).

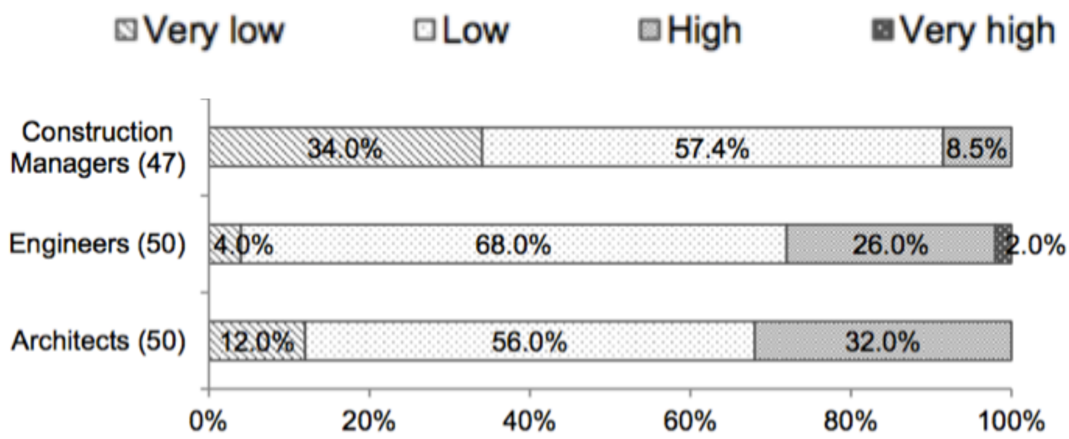


Fig.4 Perceived level of awareness among different occupations. [19]

Researsh Needs

The same survey gathered opinions about research needs in the field. Findings show that structural performance, connections, moisture performance, market/ customer research and acoustic performance are the main areas needing to be addressed. Environmental performance is surprisingly disregarded as of “medium” to “low” research priority. Visual appearance of CLT could also be problematic as one respondent puts it “Timber availability, building tradition, and clients’ perception varies a lot from country to country in Europe [...]. In Portugal, timber is expensive. Therefore, if it’s going to be used it should be seen and appreciated. But exposed CLT structures are not always very attractive, nor suitable to elaborated architectural design and raise fire [...] concerns. Besides, timber durability in Southern Europe climates and thermal performance of low-weight buildings in summer conditions are great issues in these countries.” [19]

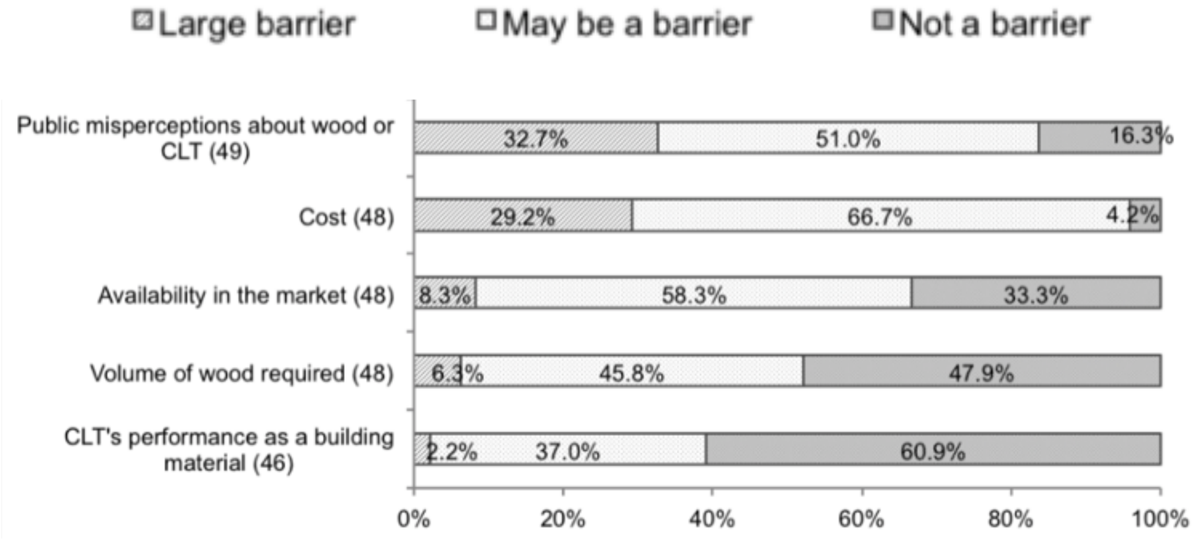


Fig.5 Perceived barriers to adoption. [19]

Installation Simplicity

CLT is usually provided, depending on the manufacturer, as large format panels with typical widths that vary between 0.6 m, 1.2 m, and 3 m. They can be delivered by request with widths up to 4~5 m. Thicknesses vary with the number of layers desired and can reach 400 mm [4]. Making use of prefabrication, CLT installation is a fast-paced assembly but the placement of connectors does require specialized knowledge. Several case studies highlighted the rapid on-site construction that may be as short as three to four days per story compared to twenty-eight days per story for typical concrete construction [22].

Fig.6 KLH Factory, Austria [17]

Structural Performance

CLT panel composition consists of orthogonal layers glued in different directions and on top of each other (fig.2). This adds stability and allows loads to be carried in both directions just like in a concrete slab. In this sense, plywood panels are very similar. The difference about CLT relies in its unique dimensional stability that allow panels to be used in load-bearing plates and shear panels, as shown in the research conducted by Steiger and Gulzow (2010). Thanks to CLT and other EWPs, wood is now regarded as a good alternative to steel and concrete in a much broader sense than it was in the past. For instance, one of the more interesting characteristics of CLT is its strength-to-weight ratio, which allows builders to build high-rise buildings

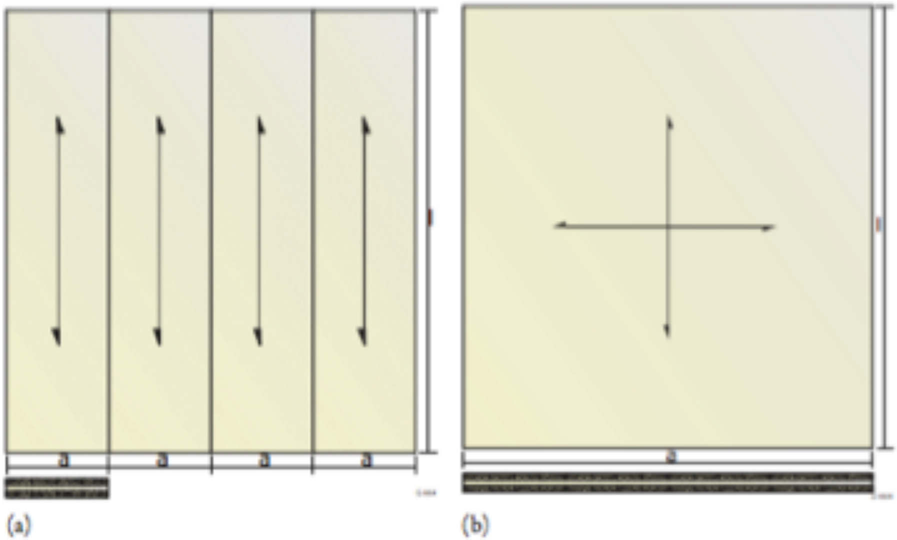
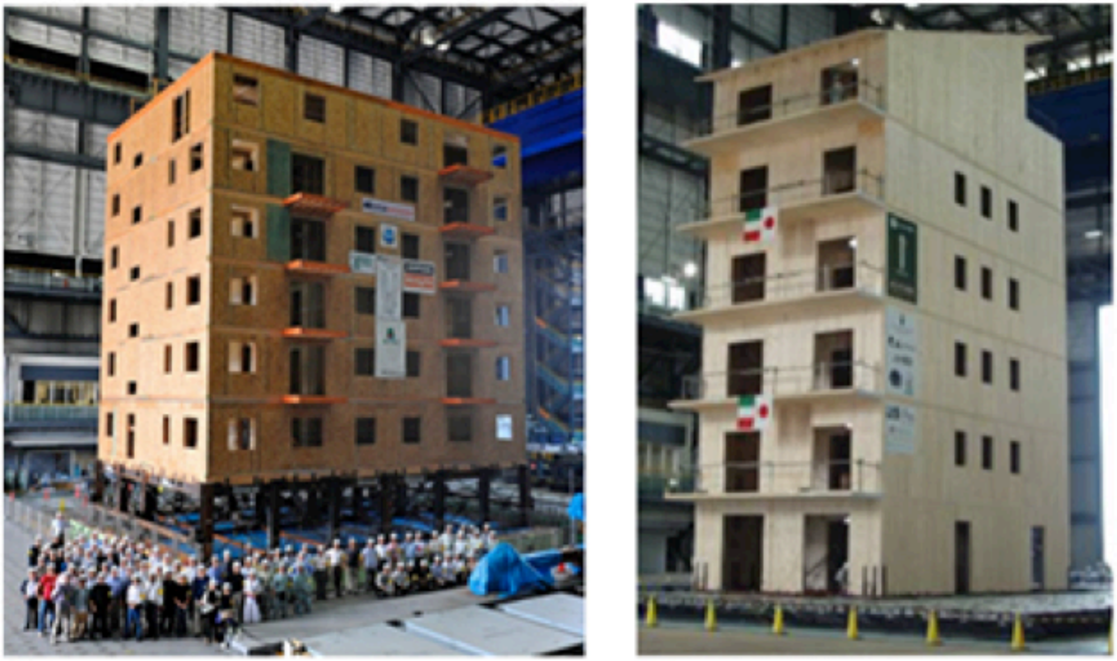


Fig.7 (A) Floor assembly of four 3-ply CLT panels acting in one direction.
(B) Floor assembly of one 3-ply CLT panel acting in two directions. [4]

Seismic Performance

It’s known that if assembled correctly CLT buildings perform well under lateral forces because most seismic forces are absorbed by multiple small connections and not by the panels themselves. Two experiments tested CLT under seismic conditions. The first was done in the US, called NEESwood Project and tested a steel-wood hybrid structure; the second was the Sophie Project and tested a full-scale six story CLT building in Japan’s largest seismic table [23]. In both experiments, no permanent deformation was found under earthquake simulations of 7.2 magnitudes in the Richter scale.



(a) (b)

Fig.8 (A) 6-stories hybrid, NEESwood Project. (B) 6-stories, SOFIE Project

Fire Performance

The fire performance of CLT panels is a very controversial matter and probably the main challenge that the product faces to get acceptance from the market. Because it is common to think that wood-based products are also highly flammable, builders often make the assumption that CLT is a highly flammable material, however that’s a misleading conclusion. Experiments performed by FPINNOVATIONS in which several CLT panels were evaluated under different fire conditions, observed that wood formed a char layer that protected non-charred wood from further thermal degradation and mass loss (fig.10). This behavior allows the structural element to maintain its strength and dimensional stability without collapsing in an abrupt way, potentially providing time for the evacuation of occupants from the building. Several other studies like the ones performed by The American Wood Council witnessed wall samples enduring more than 180 min before collapsing which largely exceeds the 90 min window required by most construction codes [24].

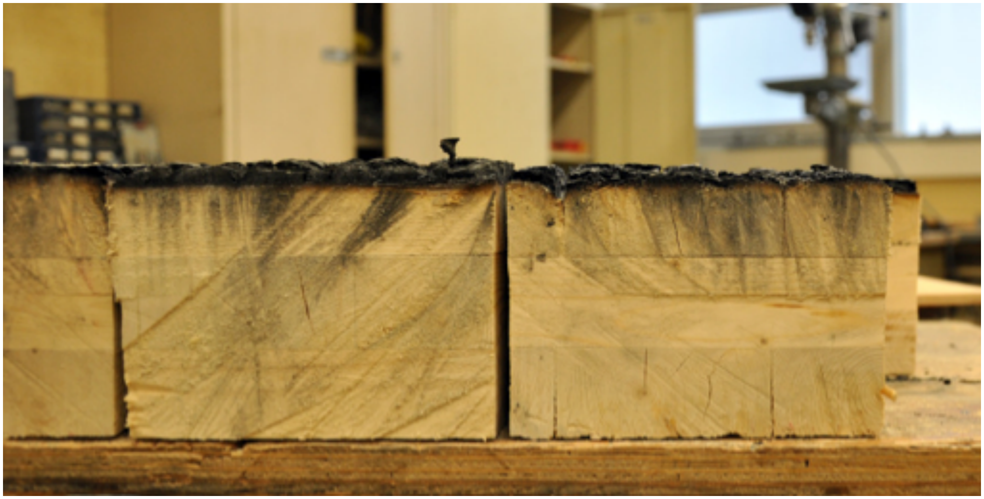


Fig.9 Fire test performed by FPINNOVATIONS [4]

Cost Competitiveness

A study [ref] aiming to determine the feasibility of CLT construction in the Pacific Northwest, compared three versions of a 10-story building and discovered CLT offered an estimated 4% cost saving when compared with a concrete alternative, and an estimated 2% when compared with a metal (light gauge frame) option. Even tough this number is not large, the CLT benchmark used in the study was not optimized for modular construction and the structure used was entirely made of CLT. If different materials are incorporated, even greater cost savings are attainable. Nevertheless, it was found that in CLT construction the material cost far outweighs the labor costs and that the main obstacle to higher savings is related with the manufacturing sector, which is not receiving enough demand to warrant the capital expense of retooling. Furthermore, the specialized knowledge required to build with CLT is estimated to have a premium cost until competency and familiarity with the material is established locally.

Tall Buildings to Date

The purpose of this chapter is to show that CLT construction is a reality and has been for several years now. Earlier examples were completed in 2005 and since then several more buildings have been completed, mainly in Europe but some in the U.S, Canada and China. Uses range from residential buildings to office and mixed-use buildings. Not meant to be exhaustive, this dissertation makes a revision of some of the most significant examples. For research purposes, an inventory of all known mid-rise and high-rise CLT buildings is provided including both completed (Table 1) and underdevelopment projects (Table 2).

Table 2 – List of mid-rise CLT buildings completed to date. (2016)

Name	Location	Studio	Use	Year	Stories
Svartamoen	Trodheim, Norway	Brendeland + Kristoffersen	Residential	2005	5
Fairmule House	Hoxton, UK	Quay2c	Residential	2005	5
MFH Holzenhausen	Steinhausen, Switzerland	Schenitlin-Syfrig + Partner Architekten AG	Residential	2006	6
E3 Place	Berlin, Germany	Kaden + Klingbiel	Residential	2008	7
Lagerhuset	Eslov, Sweden	Multiple	Residential	2008	10
Limnologe	Vaxjo, Sweden	Arkitecktbolaget Kronoberg	Residential	2008	8
Stadhaus, Murray Grove*	London, UK	Waugh Thistleton	Residential	2009	8
High-Bay Warehouse	Dornbirn, Austria	Huber	Industrial	2009	10
Édifice Fondaction	Quebec, Canada	Gilles Huot, GHA Atelier d'architecture	Office	2010	6
3xGrun Place	Berlin, Germany	Rozinskistrum	Residential	2011	5
Bridport House	London, UK	Karakusevic	Residential	2011	8
H8	Bad Aibling, Germany	Schankula Architekten	Mixed	2011	8
Walderhaus	Hamburg, Germany	Andres Heller	Mixed	2011	5
PuuEra	Heinola, Finland	Vuorelma Arkkitehdit Oy	Residential	2012	5
52 Whitmore Road	London, UK	Waugh Thistleton	Residential	2012	6
Life Cycle Tower One*	Dornbirn, Austria	Hernmann Kaufmann	Office	2012	8
UBC Earth Sciences	Vancouver, Canada	Perkins and Will	Education	2012	5
Forté Living*	Melbourne, Australia	LendLease	Residential	2012	10

*Will be reviewed here.

Table 2 – List of mid-rise CLT buildings completed to date. (cont.)

Name	Location	Studio	Use	Year	Stories
Wagramerstrasse	Vienna, Austria	Schluder Architecture	Residential	2013	7
Pentagon II	Oslo, Norway	Hoyer Finseth AS	Residential	2013	8
District 03	Quebec, Canada	EP_aArchitects	Residential	2013	6
Panorama Giustinelli	Triste, Italy	Luciano Lazzari, Alessando Fassi, Epoca S.r.l.	Residential	2013	7
Bilitt Center	Seattle, USA	The Miller Hull Partnership	Office	2013	6
Marina Verde	Caorle, Italy	Studio P + B Associati	Hotel	2013	6
Maison de l&039	Paris, France	Lipsky + Rollet	Residential	2013	7
Via Cennia di Cambiamento	Milano, Italy	Rossiprodi	Residential	2013	9
Tamedia	Zurich, Switzerland	Shigeru Ban	Office	2013	6
Wood Cube	Hamburg, Germany	Architekturagentur	Residential	2013	5
StrandParken	Stokholm, Norway	Wingardhs	Residential	2014	8
Wood Innovation and Design Centre	Prince George, Canada	Michael Green Architecture	Office	2014	6
Lintuvitta	Seinajoki, Finland	Arkkitehtuuritoimisto AT	Residential	2014	5
Kingsgate House	London, UK	Hordon Cherry Lee	Residential	2014	6
Shaing-Yang WoodTek*	Taiwan, China	WoodTek	Mixed	2014	5
Rundeskogen	Sandnes, Norway	Helen and Hard	Residential	2014	8
Illwerke Zentrum Montafon	Vandans, Austria	Hernmann Kaufmann / CREE	Office	2014	5
St. Dié-des-Vosges	St. Dié-des-Vosges, France	ASP architecture and Sertelet	Residential	2014	8
Contralaminada	Lleida, Spain	Trass Arquitetura	Residential	2014	8
UEA Student Residence	Norwich, UK	LSI Architects	Residential	2014	7
Les Docks Libres	Marseille, France	Carta Architecture	Office	2015	6
Curtain	London, UK	Waugh Thistleton	Mixed	2015	6
Verde Living	Adelaide, Australia	Proske Architects	Residential	2015	5
Cobalt	London, UK	AHMM	Residential	2015	6
Trentino-Quebec	Trento, Italy	Cost Researsh Project	Residential	2015	5
FrameWork	Portland, Oregon	Works Partnership Architecture	Office	2015	5
Banyan Warf	London, UK	Hawkins Brown	Residential	2015	10
Puukuokka	Finland	OOPEAA	Residential	2015	8
TREET*	Bergen, Norway	Artec / Sweco	Residential	2015	14
Les Closières	Charleroi, Belgium	Baneton - Garrino	Residential	2016	5
Maiha	Seinajoki, Finland	A-Live	Residential	2016	5
Rue des Ardennes	Paris, France	Audebeau and Fokkema	Residential	2016	5
The Nordic Lofts	London, UK	Amin Taha	Residential	2016	5

*Will be reviewed here.

Table 3 – List of mid-rise CLT buildings under development. (2016)

Name	Location	Studio	Use	Year	Stories
105 Punt Road	Melbourne, Australia	deciBel Architecture	Residential	UD	8
International House	Sydney, Australia	LendLease	Office	UD	6
Le Caumpus Seine	Nanterre, France	Laisné Roussel + François Leclercq	Residential	UD	6
Laisne Roussel	Paris, France	Nicolas Laisne + Sou Fujimoto	Mixed	UD	17
Ternes Villiers	Paris, France	Jacques Ferrier Architectures + Chartier Dalix Architectes	Residential	UD	17
475 West 18th	New York, United States	SHoP Architects	Residential	UD	10
HoHo*	Vienna, Austria	Rudiger Lainer	Mixed	UD	24
The Hyperion	Bordeaux, France	Jean-Paul Viguier et Associés	Residential	UD	18
Silva	Bordeaux, France	d'Art & Build + Studio Bellecour	Office	UD	18
Arbora	Montreal, France	Lemay + CHA	Residential	UD	20
Origine	Quebec, Canada	Yvan Blouin Architects	Residential	UD	13
Heartwood by the Beach	Toronto, Canada	Quadrangle	Residential	UD	6
FrameWork: Urban + Rural Ecology	Portland, Oregon	LEVER architecture	Mixed	UD	12
Carbon 12	Portland, Oregon	The Kaiser Group	Residential	UD	8
Penticton Lakeside Resort	Penticton, BC	HDR/CEI Architecture	Hotel	UD	6
Dalston Lane	London, UK	Waugh Thistleton	Residential	UD	14
Hotel Nautilus	Pesaro, Italy	Marco Gaudenzi & Associati	Hotel	UD	7
Moholt 50/50	Trodheim, Norway	Tormad Raen	Residential	UD	9
UBC Brock Commons	Vancouver, Canada	Acton Ostray	Residential	UD	18
T3	Minneapolis, Minnesota	MGA	Office	UD	7

*Will be reviewed here.

Stadhaus Murray Groove Waugh Thistletlon

Fig.10 Stadhaus, looking west along Murray Grove, London, UK. [25]

Finished in 2009, Stadhaus is one of the earliest examples of mid-rise CLT construction in Europe. The building is a nine-story residential tower in Hackney, East London. Constructed by Waugh Thistletlon Architects it was at the time of completion the tallest timber residential building in the world.

Stadhaus Murray Groove

“As a primary goal Waugh Thistleton set out to demonstrate through the project how the use of cross-laminated timber panels might be an answer to the UK’s desperate need for sustainable, high density housing. Completed within budget for Telford Homes, Stadhaus occupies a site of 17 m x 17 m and houses twenty-nine apartments: nineteen private sales units; nine affordable tenancies and one shared elegantly designed and carefully engineered ownership. It is a building that has been elegantly designed and carefully engineered to serve the needs of both its tenants and its surrounding community, complementing the East London skyline with a monochrome façade. More than that, Stadhaus is a pioneering example of architecture that points the way towards carbon-neutral, and even carbon-negative, construction. A building of this form would normally be procured as a reinforced concrete frame, an energy intensive process producing upwards of 125,000 kg of carbon. In contrast Stadhaus actually stores 185,000 kg of carbon within the timber structure. To put these figures in perspective, the usual requirement of ten per cent carbon reduction through on-site renewable energy would equate to the same saving only after 200 years of the building’s constant use. Compared to the seventy-two weeks programmed for a concrete frame design, Stadhaus took forty-nine weeks to complete. The timber structure itself was constructed in just twenty-seven days by four men, each working three-day week. Many other savings were made and it proved to be as well received on the market as it was by the client and contractors when all units sold within two hours of their launch.” [25]

Life Cycle Tower One Hernmann Kaufmann

Fig.11 LCT One, Dornbirn, Austria. [26]

Completed in 2012, LCT One was made as a case study for CLT construction. Highly prefabricated, the building left a fair contribution to the advancement of the technology by tracking the functional efficiency of the system under real terms of use. Results show that the system meets the Passive House standards.

Life Cycle Tower One

Built as a proof of concept, LCT One was developed to bless the building industry with a pre-fabricated building model, done mainly from wood. To do so, the assembly sequence was thought to be very similar to what can be found in cars and computer aided design, resulting in a highly sustainable model that can be completed in just 8 days with only 5 workers on site. Additionally, this building served as a research project for lifecycle assessment (LCA), and tracked several stages of the construction, namely the planning phase; offsite production and onsite assembly; use and conservation; dismantling and recycling. This was done because, by the time of it's construction, it was already expected that this construction system would achieve international marketability, and a pilot project serving as central building block for testing and marketing was lacking. Filling that gap, Life Cycle Tower One was built. The structural approach consisted of a reinforce concrete staircase core, 8 hybrid slabs, and a building enclosure with integrated mechanical, electrical and plumbing (MEP) systems. However, this decision was contrary to the original intent of building the entire system in wood, including the staircase core, due to fire prevention concerns. Conclusions from this research determined that LCT system could be applied as a worldwide solution, providing opportunity for less-developed countries to sustainably manage forestry stock and start manufacturing modern buildings while creating new green jobs and affordable housing not dependent on fossil fuels. To date it remains an inspiration for the building industry.

Forté Living Hernmann Kaufman

Fig.12 Forté, Melbourne, Australia. [27]

Also completed in 2012, with 10-stories (32 m), Forté remained the tallest resi- -dential timber building in the world up until 2015 when TREET was built with 14 stories. By tracking the functional efficiency and environmental performance of the building, promoters were able to create an interactive website that endorses the intrinsic value of the system and adds value to the real estate.

Forté Living

As the first Australian CLT building ever, it carries a good amount of innovation through out. The 10-story apartment building combines smart design with efficient systems to positively affect the environment, storing nearly 761 tones of CO_2 in the structure. The building is equipped with technology that can save residents an average of 265€ per year on energy and water bills [27].

Widely pitched by the promoters, this project has done a fair amount of testing on the market and proved developers that CLT construction is worthy of recognition. In a very complete presentation Lend Lease set out to demonstrate how cross-laminated timber is challenging current building practices to create buildings that are faster to erect and better for the environment. They also set out to show the attributes of CLT that can reduce a building's footprint; to understand how the use of CLT can significantly reduce the typical construction schedule of a mid-rise building and how CLT buildings contribute to sustainable communities. The ground floor of this building is made of concrete but from the 1st floor up, the centered core and the 10 slabs are made entirely out of wood. In the end, the entire building took 12 weeks and 5 specialized workers to complete. An interactive website was also created for this project, breaking down the environmental performance of the building into categories with different indicators, namely: Building materials; Water consumption; Energy efficiency; Health & Wellbeing; Shared infrastructure; Nature; Social; Transport and Economy. Due to the cold nature of Melbourne, protection from weather was key to achieve durability. The solution was to install a rain screen of aluminum panels with a cavity from CLT panel in which water drains out.

Shaig-Yang WoodTek

Fig.13 WoodTek headquarters, Taiwan, China [28]

Completed in 2014, this building belongs to WoodTek headquarters in Japan. This iconic office is the first CLT building in Asia and it's a call to action for green architecture to develop in the country. The modern look of the building broke down misconceptions about the box-like aspect of CLT architecture.

Shaig-Yang

Keeping a building dry in Taiwan is a difficult task, and as the first CLT building there, Shaig-Yang faced a series of challenges regarding the hot and humid climate. Solutions came by installing a pressure-equalized rain screen [5] around the building and elevating the ground floor over a concrete base. Structurally, the team developed a new approach and made the building with no core, unlike anything previously done in Europe. In this sense, WoodTek broke new ground on structure and aesthetics of CLT construction.

The project later did what it was originally intended to do and led to the creation of the event "Timberize Taiwan 2015", an exhibition organized by students to get Japanese academics and technologists talking about high-rise wooden architecture (fig.17). Like a forestry country, Japan has a unique opportunity to use this geographical advantage in the development of wooden buildings.

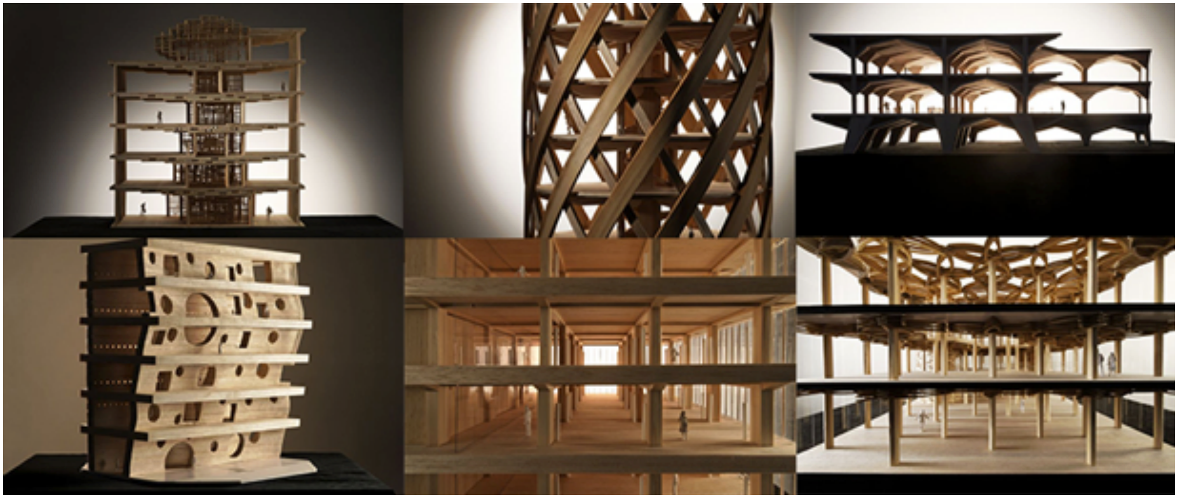


Fig.14 Timberize Taiwan 2015, selected proposals. [29]

5 A rain screen drainage plane that creates a separation (an air chamber) between the back-side of a rain screen and the exterior surface of the weather resistant barrier.

TREET/Bergen Project Artec

Fig.15 TREET/Bergen Project – Bergen, Norway [30]

Completed in 2015, this building remained the tallest residential timber in the world with 14 stories (52.8 m), until UBC Brock Commons replaced it. For the Bergen Project, Artec developed a robust design using glulam truss works and a cabinet like structure with drawers, being the drawers prefabricated houses.

TREET/Bergen Project

A pre-study made in 2008 by The Norwegian Wood Council (Tretenisk), recommended using a combination of modules made from laminated timber to build the tallest timber building in the world. This study established the basis of the Bergen project. To build this 14-storey timber apartment building in Norway it was required to place a concrete basement on the bottom to support the first 4 modules. A Framework is then placed to serve as base of the next four modules. The balconies are assembled afterwards and finished with a glass facade. Following previous logics of CLT construction, the staircase core is made in timber but is not part of the main load bearing system. The version built is one within 4 alternatives suggested by the study. The building proved itself quite good, resulting in a robust design.

UBS Brock Commons Acton Ostry Architects

Fig.16 UBS BROCK COMMONS – Vancouver, Canada [31]

Completed in 2016, this is the tallest residential timber structure on earth with 17-stories (53 m). The building envelope was completed 4 months ahead of schedule with only 70 days elapsed on site. Meant to function as student residence for 400 students in Vancouver by September 2017 work is still continuing on the interior of the building.

UBS Brock Commons

Aiming to demonstrate the potential of mass wood structures in the urban development of British Columbia (B.C), this hybrid structure combines mass wood and concrete in a unique way achieving costs comparable to those of concrete and steel buildings. Its structure consists of a one story concrete podium with two concrete staircase cores placed at the edge of the southwest view. The 17 stories are made of mass timber topped with prefabricated steel beams and a metal roof deck. The loads are shared between the two materials, leaving vertical load to the timber structure and lateral stability for the concrete cores. This innovating building happens to be the first in British Columbia to be built under the new seismic design requirements of the 2015 building code of Canada. It was calculated to rise at a rate of one floor per week and met the claims being completed in just 70 days. Brock Commons is designed to target LEED Gold certification with a total of 2,563 tones of CO2 stored in the building. Being the first to rise above six stories in Canada the building required a Site Specific Regulation (SSR) including peer reviews, leading structural engineers, fire safety experts, scientists, authorities and firefighters. It was found that the first floor and cores could have been constructed using mass timber but concrete was chosen in the interest of approval processes. The project is going to be monitored and analyzed and it is anticipated that building codes for tall wood buildings will be revised due to this event. Located in UBC's Vancouver campus, this building is part of a complex that has other wood buildings in it, namely the Engineering Student Centre, the Centre for Interactive Research of Sustainability, the Bioenergy Research and Demonstration Facility, and the Earth Sciences building [31].

HoHo Rüdiger Lainer and Partner (RLP)

Fig.17 HoHo – Vienna, Austria [32]

Located at the heart of Vienna's urban lakeside, this 24 stories (84 m) mixed-use tower is likely to become the next tallest CLT building in the world. This hybrid tower is planned to house a hotel; apartments; a restaurant; offices and a wellness center. Scheduled to 2017, 78% of the tower will be made with wood.

Haute Couture Team V Architectuur

Fig.18 Haute Couture – Netherlands [33]

Expected to rise in 2019, this 21- floors tower (74m) wants to offer occupants a lot of options for their residences, including number of floors, apartment layout, double-height spaces and optional balconies. In total, 55 apartments are accounted as well as an underground park and a public garden.

Hyperion Sou Fujimoto Architects

Fig.19 Bordeaux Tower – Bordeaux, France [34]

This tower is a joined effort of Sou Fujimoto and Laisné Roussel to build a 18-stories (50 m) tower as part of the Canopia development. The building will have 199 homes with shared spaces located on the fringes of the plot and at heart of the complex. The entire building will be prefabricated off-site. completion is expected for 2020.

Woodscraper C.F Moller Dinell Johansson

Fig.20 Woodscraper – Stockholm, Sweden [35]

Winner of the HSB Stockholm competition, this 34 stories (84 m) tower was announced to become the next big landmark of innovation in Sweden. The construction will be a residential building equipped with solar panels, a nursery, a gym, a winter garden and large public spaces. Completion is set for 2023.

BAOBAB Michael Green

Fig.21 Baobab – Paris, France [36]

This 35-story tower is a joint effort of Michael Green Architecture and DWD along with REI France, to give birth to the tallest wood building in the world. The building is placed as part of the city innovative competition Réinventer Paris. The tower will rise to put France in the forefront of wood innovation.

Trätoppen Anders Berenson

Fig.22 Treetop – Stockholm, Sweden [37]

Revealed this year, this 40 stories high (133 m) tower will be built to face the city’s fast growing population and it is designed to land on top of the Parkaden car park, earlier designed in the 1960’s. The façade is covered with numbers to help residents orient themselves within the building, using only the number of their parking spot.

London Tower PLP Architecture

Fig.23 London/Oakwood Tower – London, UK [38]

To demonstrate the potential of wood, Michael Ramage, an architect and engineer at University of Cambridge unveiled a plan for a 80-story skyscraper in London. This one-million-square-foot (93,000 m2) mixed-use has no imminent plan to be built but Ramage predicts wooden towers like this can start appearing within a decade.

3.1 Previous Research
3.2 Walls Considered
3.3 Findings

3. Previous Work

3.1 Previous Work

In previous research carried out by the research team [5], a simplified methodology was developed to determine how a set of solutions for external walls would perform according to different criteria. This approach allowed the comparison of different solutions in a way that can be easily used in early stages of an architectural project. By doing so, this methodology facilitates the decision process involved in achieving a sustainable architectural approach and shortens the hassle that a LCA assessment demands. By combining normalized values of embodied energy and carbon footprint, this procedure made it possible to attribute an overall environmental indicator to each solution as well as a generic functional indicator, attainable by putting together heat transfer coefficients and net superficial thermal mass. By assessing this kind of information, it was then possible to create a database of performance indicators for heavyweight walls. These values come as convenient when trying to compare CLT performance against current solutions. By comparing CLT walls with the solutions currently in use it is possible to draw interesting conclusions about the potential that CLT has to replace materials with a more hazardous environmental footprint. This tool considered the cradle-to-gate boundaries of a building life cycle (as the inventory database used is done under these same conditions), and easy incorporation of additional information can be done.

3.2 Criteria Chosen

The assessment of walls in this work took two main criteria into account, namely the environmental and functional performance. These criteria were chosen because they provide a clear picture of the impact each solution has in the indoor environment.
To understand each of these two criteria it’s necessary to get familiar with the concepts they depend on.

Environmental Parameters:
The environmental impact of materials is attainable by aggregation of the superficial embodied energy (EEs) and the superficial embodied carbon (ECs). These two parameters together represent the amount of energy and carbon emissions a product uses to be extracted and manufactured.
Embodied Energy:
The Embodied Energy (EEs) of materials is the amount of energy each material uses from the extraction to the factory gate, given that a cradle-to-gate approach is being considered.

$$EE_s = \sum_i \left(M_{si} \cdot EE_i\right)$$

Where,
M_{si} : Superficial mass of layer i [kg/m2];
EE_i : Embodied energy per unit mass of layer i [MJ/kg].

Embedded Carbon:

The embedded carbon (ECs) is defined as the amount of carbon dioxide (CO_2) each material releases from the extraction to the factory gate, given that a cradle-to-gate approach is being considered.

$$EC_s = \sum_i \left(M_{si} \cdot EC_i\right)$$

EC_i: Embodied carbon per unit mass of layer i [kgCO_2e /kg].

Functional Parameters:

The functional performance of wall solutions is the potential for thermal comfort and energy efficiency each wall has. This is calculated using the heat transfer coefficient (U) and net superficial thermal mass (Mtsu) associated with each individual material of the wall and then aggregated to provide an overall indicator. Unlike environmental parameters, ideal functional parameters vary according to the environment in which the wall solutions are being placed.

Energy Efficiency:

The energy efficiency of each solution is expressed by the heat transfer coefficient of each material, which represents the thermal conductivity of heat each material has. A high value of heat transfer means a lot of heat is lost, which means that, when choosing the materials for each wall assembly is necessary to be on the lookout for low values.

$$U = \frac{1}{R_{si} + \sum_i \frac{e_i}{\lambda_i} + R_{se}}$$

Where,

R_{si} : Internal surface thermal resistance [m2.K/W];

e_i : Thickness of layer i [m];

λ_i : Thermal conductivity of layer i [W/m.K];

R_{se} : External surface thermal resistance [m2.K/W].

Thermal Inertia:

Thermal inertia of walls, or the capability each wall has to absorb, retain and release heat, is attainable throw the aggregation of individual values of thermal superficial inertia (Mtsu). High values of thermal inertia take a lot of time to retain heat and so, a lot of time to release it.

R_1 : Thermal resistance of layer 1 [m2.K/W], the most external one;
M_{ts_1} : Superficial thermal mass of layer 1 [J/m2.K];
R_j : Thermal resistance of layer j [m2.K/W], located between layer 1 and layer i;
R_i : Thermal resistance of layer i [m2.K/W];
M_{ts_i} : Superficial thermal mass of layer i [J/m2.K].
R_T : Total thermal resistance of the wall [m2.K/W].

3.3 Project Scenarios

Intending to contextualize the results assessed in each wall solution, the data acquired was then related with two basic project scenarios. Scenario 1 was for cold climates where a low heat transfer is more important than thermal energy retention. In this case the functional indicator is weighted 0,90 for the U-value and 0,10 for Mtsu. Scenario 2 is for hot climates where thermal inertia acquires more importance than the U-value. In this case the functional indicator is reversed: 0,10 for the U-value and 0.90 for the Mtsu. In both cases, the environmental indicators, EEs and ECs have a weighting factor of 0,50. For each scenario two alternatives were analyzed giving greater weighting to the environmental indicator as representative of project scenarios where greater importance is given to the environmental concern. In addition, a scenario that gives priority to the carbon sequestration capability is considered, with ECs weighted 0,75 and EE's weighted 0,25. A total of six scenarios are therefore accessed according to Fig.29

Table 4 – Weighting factors for the four scenarios.

	Environmental			Functional		
	ISE	EEs	ECs	ISF	*U*	*Mtsu*
Scenario 1.1	0,50	0,50	0,50	0,50	0,90	0,10
Scenario 1.2	0,75	0,50	0,50	0,25	0,90	0,10
Scenario 2.1	0,50	0,50	0,50	0,50	0,10	0,90
Scenario 2.2	0,75	0,50	0,50	0,25	0,10	0,90

3.4 Walls Considered

Given that this research aims to compare CLT external walls with current solutions, a previously established database [5] has been used to enable the comparison. Because of this, it's important to first understand the circumstances that originate this inventory. As the author explains, solutions elected to be part of this database were selected in line with the most common Portuguese practices given a context of good construction practice and recommendations. The original sample included 90 solutions of heavyweight external walls, including booth single masonry and cavity walls. (…) The main element of these walls ranges between common hollow brick (11,15 or 20 cm); vertically perforated hollow bricks with a higher R-value (19,24 or 29cm) and concrete (20 or 30 cm). As for insulation, thicknesses vary between 4 and 6 cm and can be extruded polystyrene (XPS); black cork agglomerate or rock wool. [5]

3.5 Findings

“ The results show that, within the complete set of construction solutions analyzed in this research, the most suitable for cold climates are single brick masonry walls. Depending on the relevance attributed to the environmental impact, the type of brick may differ. If a moderate relevance is considered, thermal bricks are preferred because they lead to a lower U-value. However, if a high relevance is given to the environmental aspect, than common hollow bricks are a better choice because they have less embodied energy. In hot climates, reinforced concrete leads to a good overall ranking of these walls due to the high thermal inertia, but only if a moderate relevance is given to the environment. The also high-embodied energy and carbon of the material take these construction solutions out of the best options if a higher relevance is attributed to this indicator. In this case, single brick masonry wall are again preferred option.” [5]

4. Proposal

4.1 Framework

Due to the newness of CLT and more prominent topics needing to be addressed, the thermal and environmental performance of the material has been slightly left aside, even though information about the technology is abundant. Regarding thermal properties, it was found that the main advantage of CLT is that it offers the possibility to create an airtight assembly with a reduced number of elements and joints through which air could infiltrate or leak [15]. It's also known that thermal conductivity of wood is much lower than that of metals and it is about two to four times the thermal conductivity of mineral wool [39]. Environmentally, wood is well recognized as having clear benefits and there is a wide consensus that when forests are sustainably managed, wood is carbon-neutral, and acts as a repository of carbon, either as growing stock or as a value-added product [40]. Several studies, like the one conducted by John et al. (2009) [6] show that the carbon potential associated with CLT would allow the building to operate for the first 12 years with no net CO2 emissions. Even though the results of a survey [20] show that thermal and environmental performances are two of the less urgent problems needing to be addresses about CLT, research is still needed and useful to understand its true potential. This work intends to review the applicability of CLT and discover what's the optimal thickness and type of insulation for each given environment; this will result in the maximum net and environmental value present in the building envelope.

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6 John, S., Nebel, B., Perez, N., Buchanan, A.H., 2009. Environmental Impacts of Multi- storey Buildings Using Different Construction Materials. Report. Department of Civil and Natural Resources Engineering. University of Canterbury, Christ- church, New Zealand. (Cit. in [22])

4.2 Walls Considered

Unlike heavyweight walls, CLT walls are not included in the good practice and recommendations of the Portuguese Building Code. In order to understand and properly compare the data, CLT wall assemblies are assumed here to follow the same logic as the former, single walls with insulation as an external layer. Insulations used can be extruded polystyrene (XPS); black cork agglomerate or rock wool. The main material of the walls is a CLT panel with 19 or 24 cm thickness. Product data about CLT originated in Austrian EPD's, namely KLH, an Austrian brand witch commercializes the panels in Portugal throw a company called TISEM. This document was used to determine the thickness in which the panels are produced, the declared units and the CO2 emissions embodied in the CLT products. Even though standardized assemblies of CLT external walls don't yet exist there are some recommendations about how these assemblies should be done. It is known that in most climate zones, insulation should be placed on the external side of the CLT panels. This will keep the wood in a relatively constant warm and dry indoor environment and reduce risk of moisture damage as well as reducing expansion and contraction issues. Additionally, two types of cladding where tested and currently are the most used in CLT construction, they are: aluminum cladding (Eternit) and timber cladding. These claddings need to be nailed through wood studs that were attached to the exterior of the CLT panels. A ventilated cladding is recommended to shed rainwater and was accounted in the form of an air cavity. The sample ended up with 126 solutions and includes additional insulations that are discussed in the next chapter.

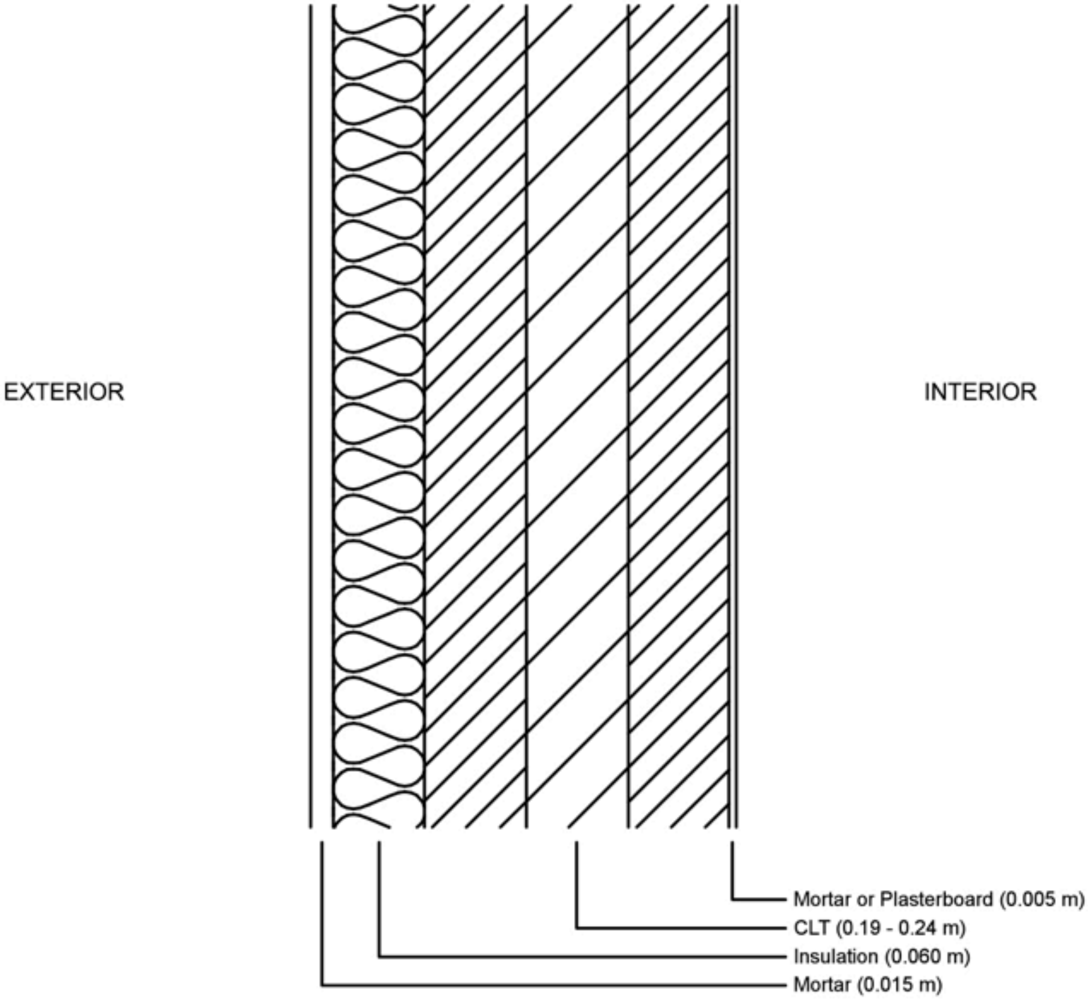

Fig.24 CLT Wall Diagram

4.3 Methodology

Making use of the same simple analysis method, briefly addressed in section 2.2, and detailed by Veludo & Rato [ref], our research process required gathering data about the materials that were intended to be tested in the wall assemblies – mostly available in the inventory database [41] – and proceed to the calculation process [5]. In the case of wood, results are particularly influenced by the carbon inclusion in the calculations made by the manufacturer. Regarding that matter, it's important to note that in this study, CLT has the carbon sequestering accounted but timber present in the battens does not. For this reason the assemblies exclude timber battens to achieve a clearer picture of the carbon potential embedded in CLT walls. In this way, the results obtained are not exhaustively accurate. However, it should be noted that a simplified methodology does originate valid outputs supporting conclusions that, overall, are no different from those obtained from a more holistic approach [42] [43] The first phase of the calculations was made

5. Results

5.1 Interpretation of the Results

As described before, the results are contextualized in two main project scenarios. Scenario 1 is for cold climates where a low heat transfer is more important than thermal energy retention and Scenario 2 is for hot climates where thermal inertia acquires more importance than the U-value. For both Scenarios an alternative was analyzed giving greater weighting to the environmental indicator as representative of project scenarios where greater importance is given to the environmental concern.

Table 5 – Weighting factors for the four scenarios.

	Environmental			Functional		
	ISE	EEs	ECs	ISF	*U*	*Mtsu*
Scenario 1.1	0,50	0,50	0,50	0,50	0,90	0,10
Scenario 1.2	0,75	0,50	0,50	0,25	0,90	0,10
Scenario 2.1	0,50	0,50	0,50	0,50	0,10	0,90
Scenario 2.2	0,75	0,50	0,50	0,25	0,10	0,90

The results should be interpreted as the following:

The blue bar represents an overall Functional Indicator with the aggregated results of the Functional Parameters.

The green bar represents an overall Environmental Indicator with the aggregated results of the Environmental Parameters.

The grey bar combines environmental and functional parameters to produce a single sustainability index that characterizes each of the construction solutions.

5.2.1 Cold Climates

Table 6 – Results from Scenario 1.1.

CLT walls	Description	U	m tsu	EEs	ECs	TOTAL
CLT (External.Ins.)	Rockwool(6 cm)+CLT(19 cm)	0,29	118	2513	-140	0,65
CLT (External.Ins.)	XPS(6 cm)+CLT(19 cm)	0,28	119	2559	-140	0,65
CLT (External.Ins.)	Rockwool(6 cm)+CLT(19 cm)+Plasterboard (5 cm)	0,29	113	2529	-140	0,64
CLT (External.Ins.)	XPS(6 cm)+CLT(19 cm)+ Plasterboard (0,5cm)	0,28	114	2574	-141	0,64
CLT (External.Ins.)	Rockwool(6 cm)+CLT(24 cm)	0,26	142	3134	-181	0,63

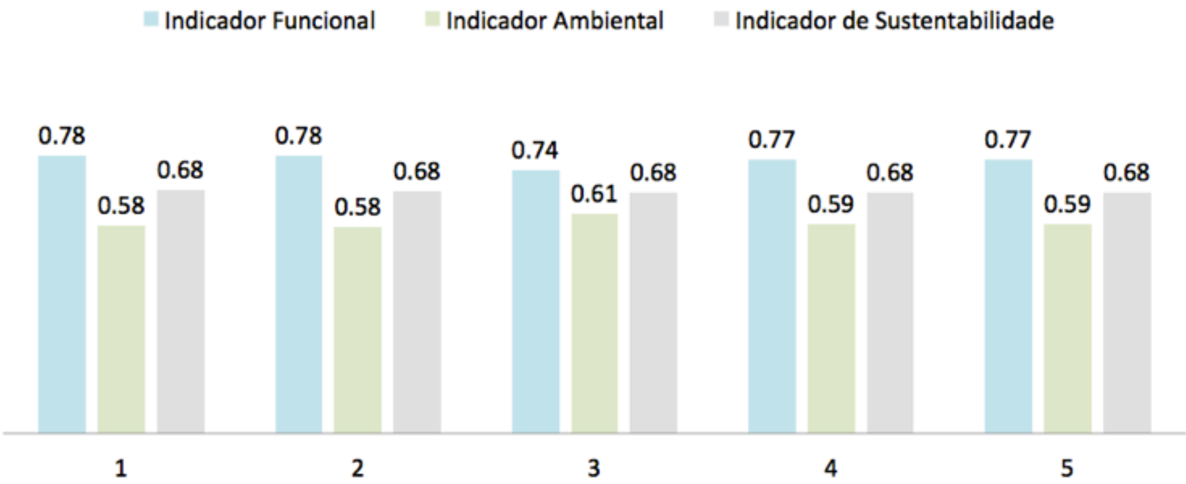

Fig25 Results from Scenario 1.1

5.2.1 Cold Climates with environmental concern

Table 7 – Results from Scenario 1.2

CLT walls	Description	U	m tsu	EEs	ECs	TOTAL
CLT (External.Ins.)	Rockwool(6 cm)+CLT(19 cm)	0,29	118	2513	-140	0,65
CLT (External.Ins.)	XPS(6 cm)+CLT(19 cm)	0,28	119	2559	-140	0,65
CLT (External.Ins.)	Rockwool(6 cm)+CLT(19 cm)+Plasterboard (5 cm)	0,29	113	2529	-140	0,64
CLT (External.Ins.)	XPS(6 cm)+CLT(19 cm)+ Plasterboard (0,5cm)	0,28	114	2574	-141	0,64
CLT (External.Ins.)	Rockwool(6 cm)+CLT(24 cm)	0,26	142	3134	-181	0,63

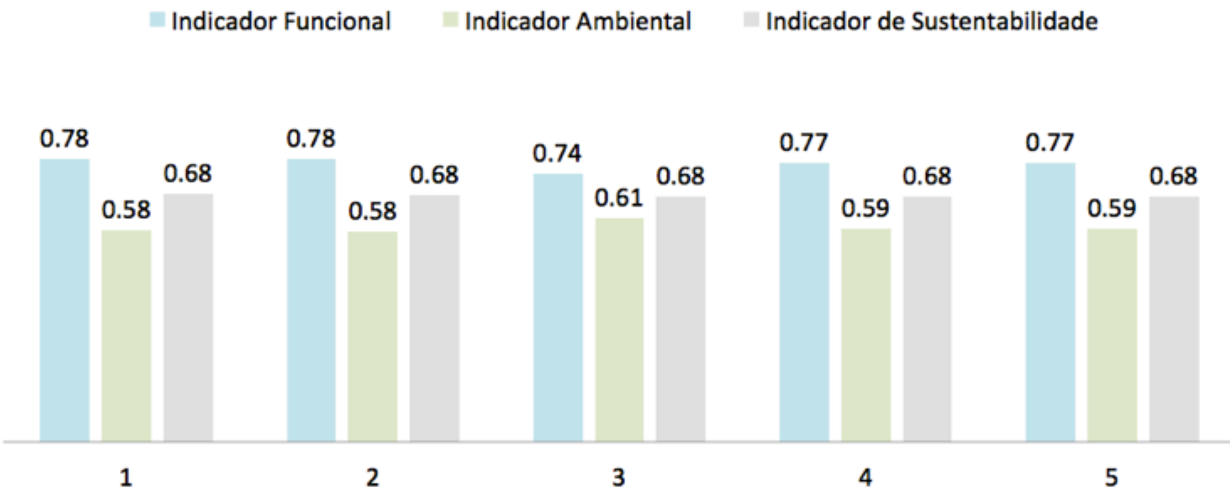

Fig.26 Results from Scenario 1.2

5.2.2 Hot Climates

Table 8 – Results from Scenario 2.1.

CLT walls	Description	U	m tsu	EEs	ECs	TOTAL
CLT (External.Ins.)	Rockwool(6 cm)+CLT(24 cm)	0,26	142	3134	-181	0,41
CLT (External.Ins.)	XPS(6 cm)+CLT(24 cm)	0,25	144	3180	-182	0,41
CLT (External.Ins.)	Rockwool(6 cm)+CLT(19 cm)	0,29	118	2513	-140	0,41
CLT (External.Ins.)	XPS(6 cm)+CLT(19 cm)	0,28	119	2559	-140	0,41
CLT (External.Ins.)	Rockwool(6 cm)+CLT(24 cm)+Plasterboard (5 cm)	0,26	137	3150	-183	0,41

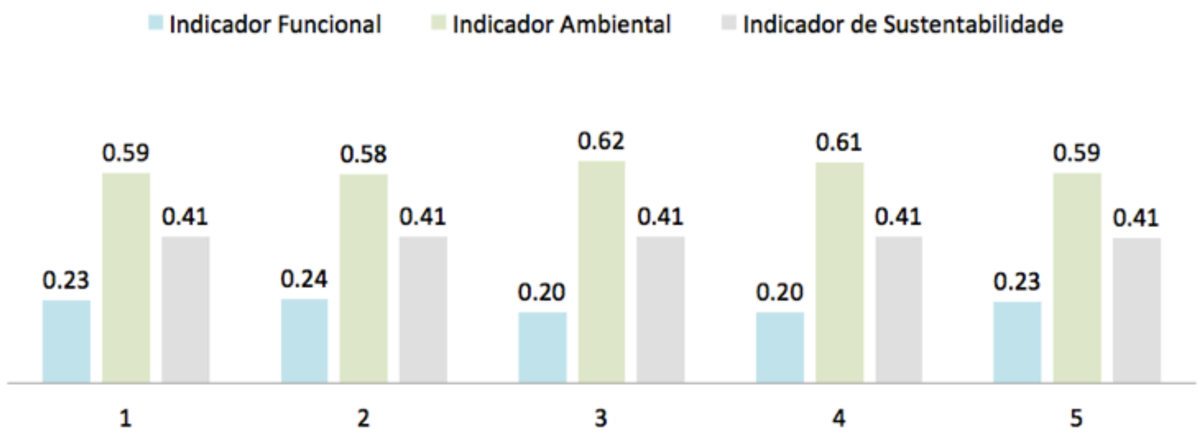

Fig.27 Results from Scenario 2.1

5.2.2 Hot Climates with environmental concern

Table 9 – Results from Scenario 2.2

CLT walls	Description	U	m tsu	EEs	ECs	TOTAL
CLT (External.Ins.)	Rockwool(6 cm)+CLT(19 cm)	0,29	118	2513	-140	0,51
CLT (External.Ins.)	Rockwool(6 cm)+CLT(19 cm)+Plasterboard (5 cm)	0,29	113	2529	-140	0,51
CLT (External.Ins.)	XPS(6 cm)+CLT(19 cm)	0,28	119	2559	-140	0,51
CLT (External.Ins.)	Rockwool(4 cm)+CLT(20 cm)	0,34	115	2617	-150	0,51
CLT (External.Ins.)	XPS(6 cm)+CLT(19 cm)+Plasterboard (5 cm)	0,28	114	2574	-141	0,51

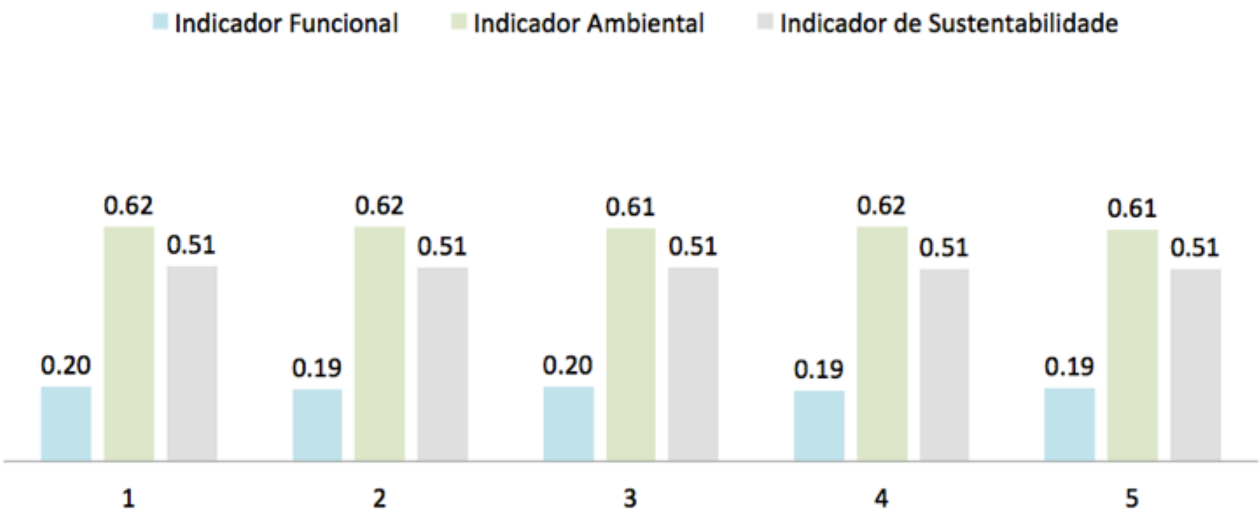

Fig.28 Results from Scenario 2.2

5.3 Comparison

As the main intent of this work was to compare CLT walls with current solutions the following results were attained by combining in the same calculation sheet both the CLT walls from this work and the heavyweight walls from the previous one. [ref.] For each given scenario (1.1;1.2;1.3;1.4) the top 5 solutions are presented.

5.3.1 Cold Climates

Table 10 – Results from Scenario 1.1.

CLT walls	Description	U	m tsu	EEs	ECs	TOTAL
CLT (External.Ins.)	Rockwool(6 cm)+CLT(19 cm)	0,29	118	2513	-140	0,65
CLT (External.Ins.)	XPS(6 cm)+CLT(19 cm)	0,28	119	2559	-140	0,65
CLT (External.Ins.)	Rockwool(6 cm)+CLT(19 cm)+Plasterboard (5 cm)	0,29	113	2529	-140	0,64
CLT (External.Ins.)	XPS(6 cm)+CLT(19 cm)+ Plasterboard (0,5cm)	0,28	114	2574	-141	0,64
CLT (External.Ins.)	Rockwool(6 cm)+CLT(24 cm)	0,26	142	3134	-181	0,63

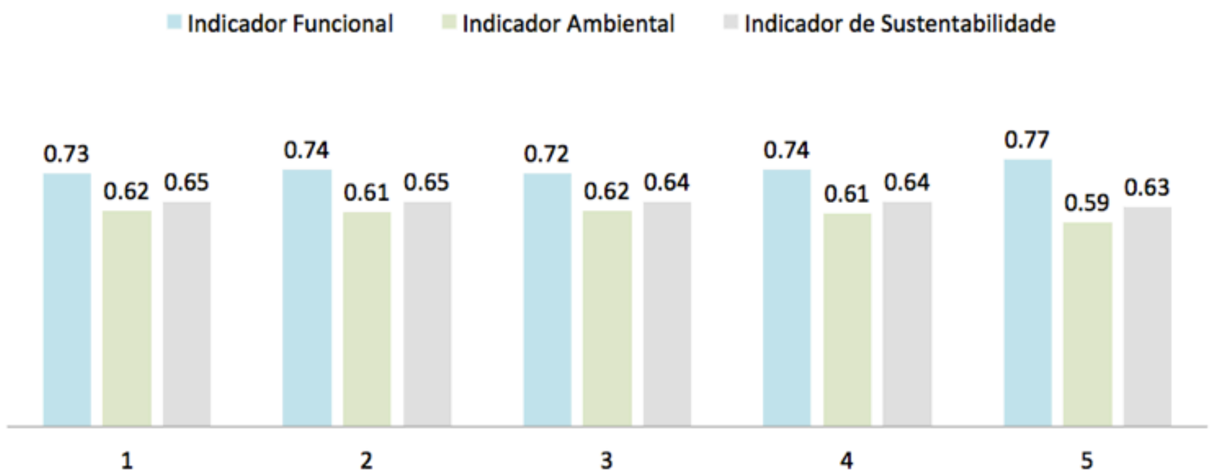

Fig.29 Results from Scenario 1.1

5.3.2 Cold Climates with environmental concern

Table 11 – Results from Scenario 1.2

CLT walls	Description	U	m tsu	EEs	ECs	TOTAL
CLT (External.Ins.)	XPS(6 cm)+CLT(24 cm)	0,25	144	3180	-182	0,68
CLT (External.Ins.)	XPS(6 cm)+CLT(24 cm)+ Plasterboard (0,5cm)	0,25	138	3196	-183	0,68
CLT (External.Ins.)	XPS(6 cm)+CLT(19 cm)	0,28	119	2559	-140	0,68
CLT (External.Ins.)	Rockwool(6 cm)+CLT(24 cm)	0,26	142	3134	-181	0,68
CLT (External.Ins.)	Rockwool(6 cm)+CLT(24 cm)+Plasterboard (5 cm)	0,26	137	3150	-183	0,68

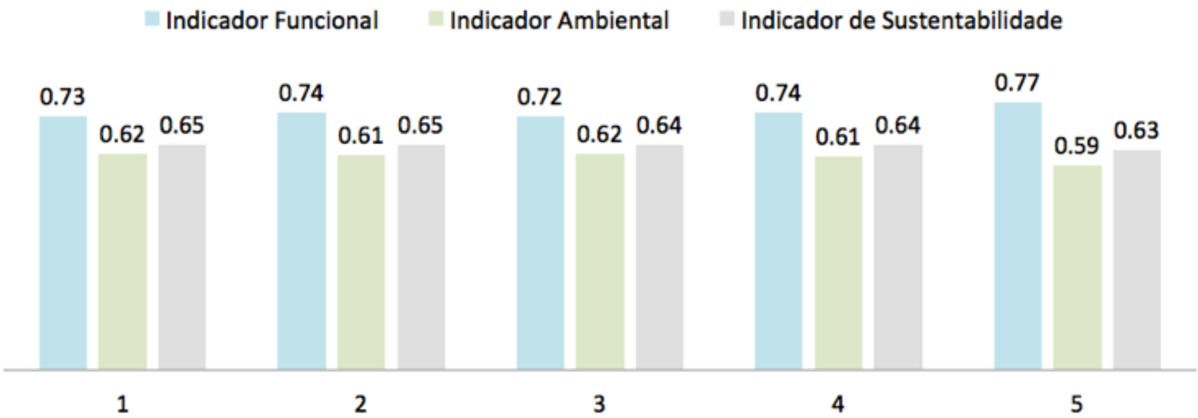

Fig.30 Results from Scenario 1.2

5.3.2 Hot Climates

Table 11 – Results from Scenario 2.1

CLT walls	Description	U	m tsu	EEs	ECs	TOTAL
Concrete (isol. Exterior)	Cork(6 cm)+Concrete(30 cm)	0,60	660	1739	168	0,63
Concrete (isol. Exterior)	XPS(6 cm)+Concrete(30 cm)	0,51	670	1925	176	0,62
Concrete (isol. Exterior)	XPS(4 cm)+Concrete(30 cm)	0,71	639	1854	173	0,60
Concrete (isol. Exterior)	Cork(4 cm)+Concrete(30 cm)	0,82	624	1730	168	0,59
Concrete (isol. Exterior)	Cork(6 cm)+Concrete(20 cm)	0,62	447	1173	113	0,55

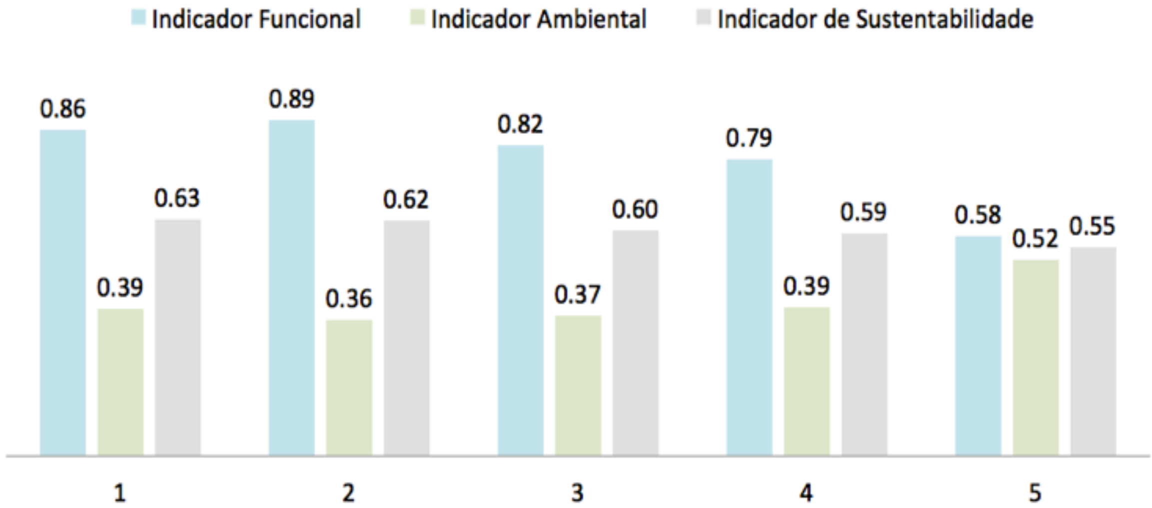

Fig.31 Results from Scenario 2.1

5.2.2 Cold Climates with environmental concern

Table 12 – Results from Scenario 2.2

CLT walls	Description	U	m tsu	EEs	ECs	TOTAL
Brick (isol. Exterior)	Cork (6 cm)+Hollow Brick(20 cm)	0,49	113	515	45	0,55
Brick (isol. Exterior)	Cork (4 cm)+Hollow Brick(20 cm)	0,63	105	506	44	0,54
Brick (isol. Exterior)	Cork (6 cm)+Hollow Brick(19 cm)	0,41	123	595	51	0,54
Concrete(isol. Exterior)	Cork (6 cm)+Concrete(20 cm)	0,62	447	1173	113	0,54
Brick (isol. Exterior)	Cork(6 cm)+Hollow Brick(19 cm)	0,51	114	586	51	0,53

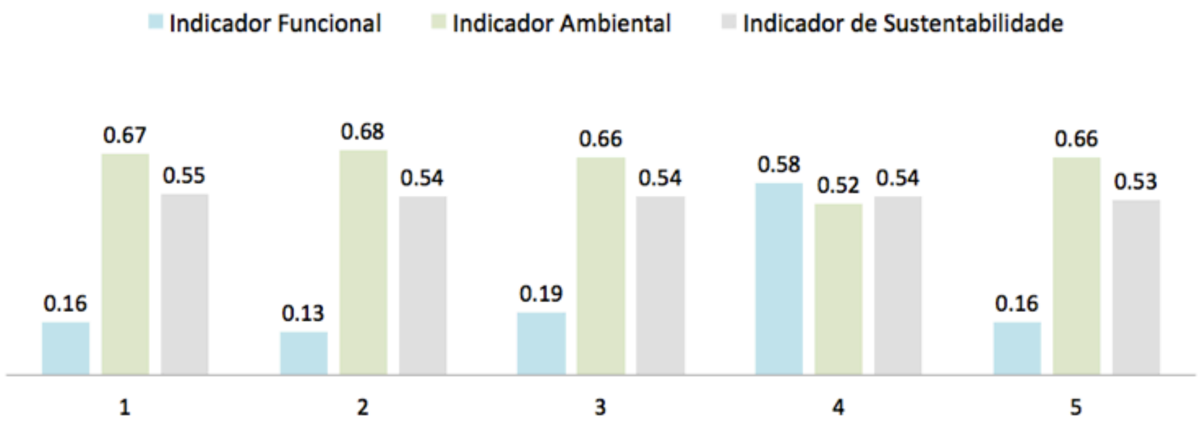

Fig.32 Results from Scenario 2.2

DISCUSSION

Scenario 1.1 – Cold Climates

The results indicate that the best choice is a to use a thicker CLT panel with 24 cm and 6 cm of XPS thermal insulation. In this case, there is also no difference in applying a mortar render or instead plasterboard as internal finishing.

Scenario 1.2 – Cold Climates with Environmental Concern

If the environmental concern is given a priority of 75% (scenario 1.2), two main differences arise from the results. First, since the CLT panels are providing most of the environmental value, the main difference between the two sets relies on the thickness of the panel. Second, cork doesn't show up in neither sets due to the overall lack of performance because the environmental impact is not so relevant like in current solutions because CLT carries most of the significance in the global value. Figures 34 and 35 provide a description of each assembly with layers and thicknesses (cm).

Scenario 2.1 – Hot Climates
In this scenario, the results indicate that the best choice is also to use a thicker CLT panel with 24 cm and 6 cm of thermal insulation. In a hot climate performance drops significantly though. This is because CLT has much smaller values for the net superficial thermal mass.

Scenario 2.2 – Hot climates with environmental concern
If the environmental concern is given a priority of 75% (scenario 1.2), the same differences arise from the results. First, thinner CLT panels are preferred with 19 cm, because the thickness of the panel influences the environmental output. Second, the same results about cork confirm that its overall performance does not offset the significance of the CLT environmental impact. Plus, if panels with 20 cm are used, thinner thermal insulation with 4 cm is recommended. Figures 42 & 43 provide a description of each assembly with layers and thicknesses (cm).

Scenario 1.1 – Cold Climates

The results show that for cold climates, CLT walls are always a preferred solution because they perform well under these conditions and have the best environmental value. Together with CLT panels, XPS appears as a more suitable insulation.

Scenario 1.2 – Cold Climates with Environmental Concern

If the environmental concern is given a priority of 75% (scenario 1.2), a hollow brick wall appears as the fifth preferred option. In this scenario, the better ranked solutions are again thinner CLT panels, with or without Plasterboard and 6 cm insulation. Figures 46 and 47 provide a description of each assembly with layers and thicknesses (cm).

Scenario 2.1 – Hot Climates

The results show that for hot climates, concrete walls are preferred because of the highest values of net superficial thermal mass. However, concrete solutions show a much worse environmental performance.

Scenario 2.2 – Hot climates with environmental concern

If the environmental concern is given a priority of 75% (scenario 2.2), the preferred choices become 20 cm and 19 cm hollow brick masonries with thermal insulation of 6 cm and 4 cm. Just one concrete wall appears in this scenario with a thermal insulation of 6 cm. This is due to the fact that concrete walls have high-embodied energy and embodied carbon. Figures 50 and 51 provide a description of each assembly with layers and thicknesses (cm).

CONCLUSIONS

The present research set out to demonstrate the functional and environmental performance of CLT walls as well as the potential of the technology to support sustainable urban growth. This was considered important to understand the impact of choosing suitable wall solutions in buildings, particularly in CLT buildings, and finding out in witch environments CLT works best is also important to comprehend the potential of CLT technology in urban infill worldwide.

Regarding thermal and environmental performance of CLT walls, it was found that its behavior is very similar to that of Hollow Brick, both in cold and hot climates. In cold climates CLT walls come out as preferable but in hot climates concrete walls are far more effective in terms of thermal behavior, even tough environmental value is significantly worse (about double that of CLT). In such a climate, choosing to go with concrete, brick or CLT depends on the goals intended for the building. If willing to sacrifice thermal performance in detriment of environmental, CLT walls are preferred to those of Hollow Brick because wood has the added value of storing carbon. It should be noted that, although CLT panels need a lot of energy to be produced, the sequestered carbon is enough to offset energy-related embodied carbon. Due to the extraordinary performance of CLT in cold climates, its not surprising that most examples of CLT construction, as well as research hubs, are located in Northern Europe, where cold climates are dominant.

Regarding the potential of the technology, it was found that the exponential growth of popularity reaching out Australia, New Zealand, Japan and North America is justified due to the pre-fabricated nature of the system that makes for rapid construction time with minimal workforce and noise pollution.

The structural behavior of the system can than meet building codes. Moreover, the carbon storage capability of the panels, storing huge amounts of carbon, is enough to offset energy production-related carbon emissions. In this sense, CLT can be considered a promising material with several economic and environmental advantages over other materials. However, his applicability is not global and is for the time being reserved to colder environments. However, scientific and technical undergoing developments regarding thermal energy storage (like phase-change materials) may be an important support to the use of CLT panels in hot climates; in this case, thermal inertia is not dependent on the weight of construction assemblies, but on other materials in the building that are included in furniture, internal finishings, etc. Even though that by the time this research was developed 17-stories is the tallest a CLT building has achieved, several projects appeared in the last few years igniting the race to build the tallest CLT building in the World. Due to this, CLT is anticipated to grow its influence in the architectural community as building codes start to embrace the material.

The main research needing to be done is a LCA study evaluating the entire life cycle of a CLT building, which is currently inexistent. Regarding thermal inertia of CLT, research is recommended in the development of panels with added materials to the composition, in a way that can increase both moisture and thermal performance of the building envelope. Also, since CLT panels have low thermal inertia, they can’t replace hazardous materials in hot climates. Due to this, the objective of reducing environmental impact of construction solutions in hot climates is not yet fully met and research to find viable alternatives is also recommended.

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ANNEX

PAREDES PESADAS	Nº	DESCRIÇÃO	VALORES AGREGADOS Funcional	Ambiental	TOTAL
Simples (isol. Exterior)	61	Reb.+XPS4+BA20	0,21	0,35	0,31
Simples (isol. Exterior)	62	Reb.+Agl.negro4+BA20	0,06	0,36	0,29
Simples (isol. Exterior)	63	Reb.+XPS6+BA20	0,47	0,34	0,37
Simples (isol. Exterior)	64	Reb.+Agl.negro6+BA20	0,36	0,36	0,36
Simples (isol. Exterior)	65	Reb.+XPS4+BA30	0,28	0,23	0,24
Simples (isol. Exterior)	66	Reb.+Agl.negro4+BA30	0,14	0,24	0,22
Simples (isol. Exterior)	67	Reb.+XPS6+BA30	0,53	0,22	0,30
Simples (isol. Exterior)	68	Reb.+Agl.negro6+BA30	0,42	0,24	0,28
Simples (isol. Exterior)	69	Reb.+XPS4+Tij.T19+Reb.	0,51	0,49	0,49
Simples (isol. Exterior)	70	Reb.+Agl.negro4+Tij.T19+Reb.	0,45	0,50	0,49
Simples (isol. Exterior)	71	Reb.+XPS4+Tij.T19+PGC	0,55	0,47	0,49
Simples (isol. Exterior)	72	Reb.+Agl.negro4+Tij.T19+PGC	0,50	0,49	0,49
Simples (isol. Exterior)	73	Reb.+Lã4+Tij.T19+PGC	0,54	0,48	0,50
Simples (isol. Exterior)	74	Reb.+XPS6+Tij.T19+Reb.	0,63	0,48	0,51
Simples (isol. Exterior)	75	Reb.+Agl.negro6+Tij.T19+Reb.	0,58	0,50	0,52
Simples (isol. Exterior)	76	Reb.+XPS6+Tij.T19+PGC	0,65	0,46	0,51
Simples (isol. Exterior)	77	Reb.+Agl.negro6+Tij.T19+PGC	0,60	0,48	0,51
Simples (isol. Exterior)	78	Reb.+Lã6+Tij.T19+PGC	0,64	0,48	0,52
Simples (isol. Exterior)	79	Reb.+XPS4+Tij.20+Reb.	0,39	0,50	0,47
Simples (isol. Exterior)	80	Reb.+Agl.negro4+Tij.20+Reb.	0,30	0,52	0,46
Simples (isol. Exterior)	81	Reb.+XPS4+Tij.20+PGC	0,45	0,49	0,48
Simples (isol. Exterior)	82	Reb.+Agl.negro4+Tij.20+PGC	0,37	0,50	0,47
Simples (isol. Exterior)	83	Reb.+Lã4+Tij.20+PGC	0,42	0,50	0,48
Simples (isol. Exterior)	84	Reb.+XPS6+Tij.20+Reb.	0,55	0,49	0,51
Simples (isol. Exterior)	85	Reb.+Agl.negro6+Tij.20+Reb.	0,47	0,51	0,50
Simples (isol. Exterior)	86	Reb.+XPS6+Tij.20+PGC	0,59	0,48	0,51
Simples (isol. Exterior)	87	Reb.+Agl.negro6+Tij.20+PGC	0,52	0,50	0,51
Simples (isol. Exterior)	88	Reb.+Lã6+Tij.20+PGC	0,56	0,49	0,51
Simples (isol. Exterior)	89	Reb.+XPS4+Tij.T24+Reb.	0,55	0,46	0,49
Simples (isol. Exterior)	90	Reb.+Agl.negro4+Tij.T24+Reb.	0,50	0,48	0,49
Simples (isol. Exterior)	91	Reb.+XPS4+Tij.T24+PGC	0,59	0,45	0,49
Simples (isol. Exterior)	92	Reb.+Agl.negro4+Tij.T24+PGC	0,55	0,47	0,49

Simples (isol. Exterior)	93	Reb.+Lã4+Tij.T24+PGC	0,58	0,46	0,49
Simples (isol. Exterior)	94	Reb.+XPS6+Tij.T24+Reb.	0,65	0,46	0,51
Simples (isol. Exterior)	95	Reb.+Agl.negro6+Tij.T24+Reb.	0,60	0,48	0,51
Simples (isol. Exterior)	96	Reb.+XPS6+Tij.T24+PGC	0,68	0,44	0,50
Simples (isol. Exterior)	97	Reb.+Agl.negro6+Tij.T24+PGC	0,64	0,47	0,51
Simples (isol. Exterior)	98	Reb.+Lã6+Tij.T24+PGC	0,67	0,46	0,51
Simples (isol. Exterior)	99	Reb.+XPS4+Tij.T29+Reb.	0,62	0,44	0,48
Simples (isol. Exterior)	100	Reb.+Agl.negro4+Tij.T29+Reb.	0,59	0,46	0,49
Simples (isol. Exterior)	101	Reb.+XPS4+Tij.T29+PGC	0,65	0,43	0,48
Simples (isol. Exterior)	102	Reb.+Agl.negro4+Tij.T29+PGC	0,62	0,44	0,49
Simples (isol. Exterior)	103	Reb.+Lã4+Tij.T29+PGC	0,64	0,44	0,49
Simples (isol. Exterior)	104	Reb.+XPS6+Tij.T29+Reb.	0,71	0,43	0,50
Simples (isol. Exterior)	105	Reb.+Agl.negro6+Tij.T29+Reb.	0,67	0,45	0,51
Simples (isol. Exterior)	106	Reb.+XPS6+Tij.T29+PGC	0,72	0,42	0,49
Simples (isol. Exterior)	107	Reb.+Agl.negro6+Tij.T29+PGC	0,69	0,44	0,50
Simples (isol. Exterior)	108	Reb.+Lã6+Tij.T29+PGC	0,71	0,43	0,50

PAREDES PESADAS	Nº	DESCRIÇÃO	VALORES AGREGADOS Funcional	Ambiental	TOTAL
CLT (External.Ins.)	1	reb.rock.wool.CLT.19.reb	0,73	0,68	0,69
CLT (External.Ins.)	2	reb.EPS.CLT.19.reb	0,74	0,68	0,69
CLT (External.Ins.)	3	reb.Cork.CLT.19.reb	0,38	0,69	0,61
CLT (External.Ins.)	4	reb.rock.wool.CLT.19.plaster	0,72	0,68	0,69
CLT (External.Ins.)	5	reb.EPS.CLT.19.plaster	0,74	0,68	0,69
CLT (External.Ins.)	6	reb.Cork.CLT.19.plaster	0,39	0,69	0,61
CLT (External.Ins.)	7	reb.rock.wool.CLT.24.reb	0,77	0,71	0,72
CLT (External.Ins.)	8	reb.EPS.CLT.24.reb	0,78	0,71	0,72
CLT (External.Ins.)	9	reb.Cork.CLT.24.reb	0,51	0,72	0,66
CLT (External.Ins.)	10	reb.rock.wool.CLT.24.plaster	0,77	0,71	0,72
CLT (External.Ins.)	11	reb.EPS.CLT.24.plaster	0,78	0,71	0,72
CLT (External.Ins.)	12	reb.Cork.CLT.24.plaster	0,52	0,72	0,67
CLT (External.Ins.)	13	reb.rock.wool.4.CLT.20.reb	0,66	0,69	0,68
CLT (External.Ins.)	14	reb.EPS.4.CLT.20.reb	0,68	0,69	0,69
CLT (External.Ins.)	15	reb.Cork.4.CLT.20.reb	0,40	0,70	0,62
CLT (External.Ins.)	16	reb.rock.wool.4.CLT.20.plaster	0,66	0,69	0,68
CLT (External.Ins.)	17	reb.EPS.4.CLT.20.plaster	0,67	0,69	0,68
CLT (External.Ins.)	18	reb.Cork.4.CLT.20.plaster	0,41	0,69	0,62