EMBODIED CARBON AND THE CLIMATE IMPACT OF OUR HOUSING

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Housing Agency Research Programme
This research is carried out with the generous assistance of the Housing Agency's Research Programme, that promotes research projects that explore current issues in housing and have the potential to positively impact housing policy and practice. The proposed research has been specifically aligned with the Housing Agency's research theme three 'Sustainable Communities', but also addresses sub-theme 1c that deals with 'Land efficiency and use.

Acknowledgments and thanks
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About the author
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Philip Comerford studied architecture in Dublin and London. He has worked as an architect in Ireland and Europe, and currently runs his own architecture studio as Philip Comerford Architect, specialising in bespoke residential developments and planning consultancy. He combines architectural practice with research interests at the intersection of housing and environmental policy. He is currently undertaking research on sustainable housing in UCD, as part of a funded research project to promote low-carbon compact urban growth in Ireland.

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Design by Lands

The Housing Agency's purpose is to provide expertise and solutions to help deliver sustainable communities throughout Ireland. A strategic objective is to support stakeholders with evidence informed insights and data to develop a sustainable Irish housing system. In this vein, the Research Support Programme funds research projects which respond to key topical issues in housing and have the potential to impact on housing policy and practice. The views expressed in this report are those of the author(s) and do not necessarily represent those of The Housing Agency.

An Ghníomhaireacht Tithíochta
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1 EXECUTIVE SUMMARY

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The housing crisis and the climate crisis are intertwined, and we cannot solve one without addressing the other. This research studies the environmental impact of new housing construction in Ireland by assessing the embodied carbon emissions of different dwelling types at a range of scales and densities, from individual houses to duplex dwellings and apartments. Current policy in Ireland focuses mainly on the emissions created by the running of buildings, known as operational carbon and measured through the Building Energy Rating (BER) system. Less well understood is the carbon emitted through the construction and maintenance of buildings, known as embodied carbon. The research addresses this gap by assessing the embodied carbon emissions and other environmental impacts created by new construction. By gaining an understanding of the climate impacts of current building practices, strategies for a decarbonised housing sector are then proposed. This evidence-based knowledge will provide developers, policy makers and housing stakeholders with a platform to imagine the low-carbon communities of the future.

An innovative aspect of the study is that in addition to measuring the environmental impact of dwellings themselves, the surrounding neighbourhood is also considered together with its external landscaping and road infrastructure. The research therefore connects climate emissions to questions of land use and density, in the context of the Irish government's policy to promote compact growth in the National Planning Framework [1]. The research first measured the embodied carbon of selected residential typologies found in county Dublin. The external areas and landscaping that surround them was then evaluated in a separate neighbourhood-scale study, and the results were combined to provide a holistic picture of the construction impact of each type. The main themes and findings to emerge from the study are summarised on the following pages.

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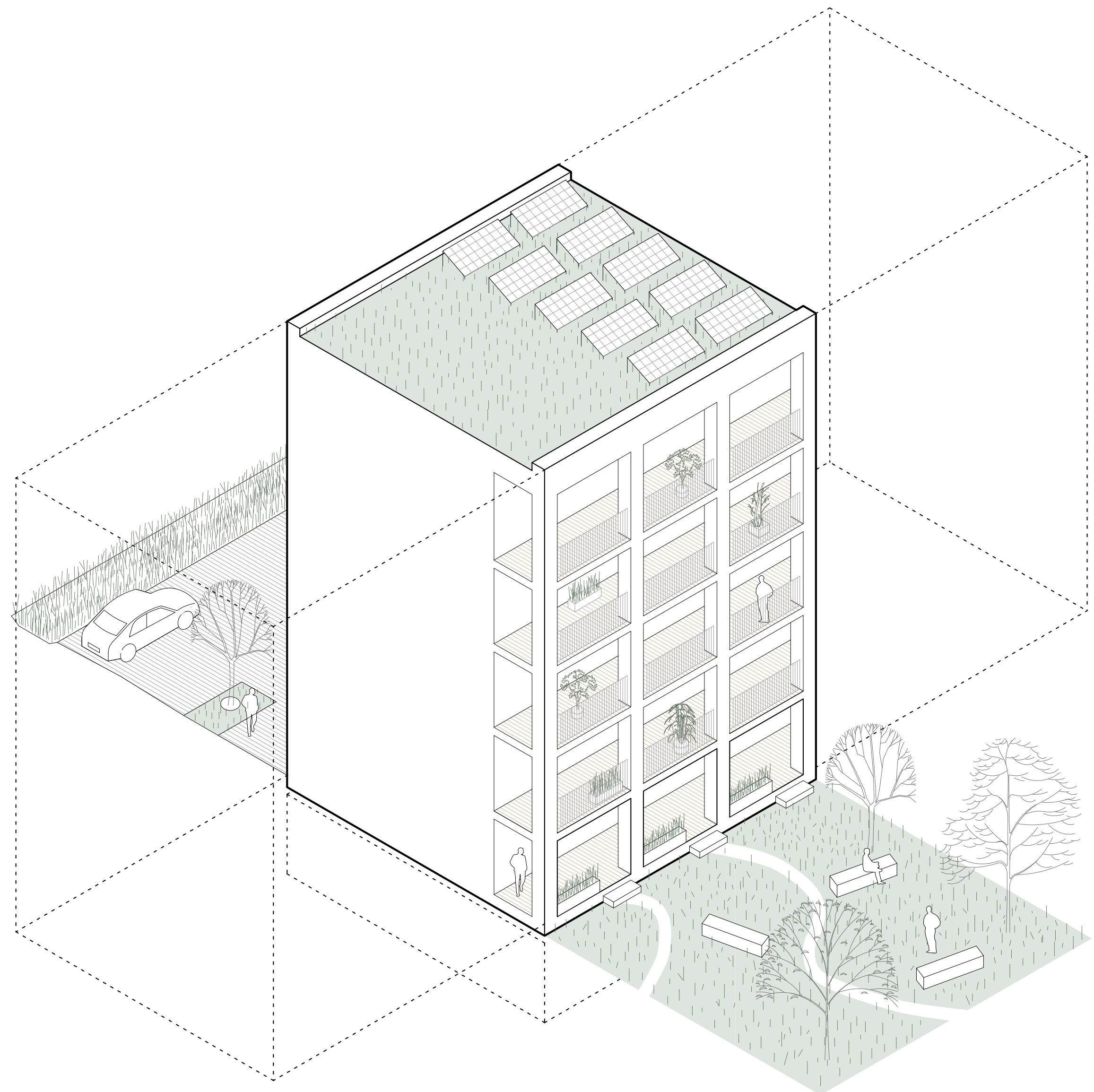

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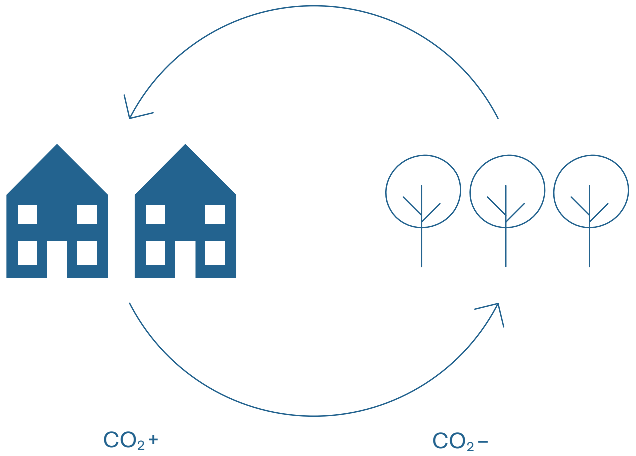
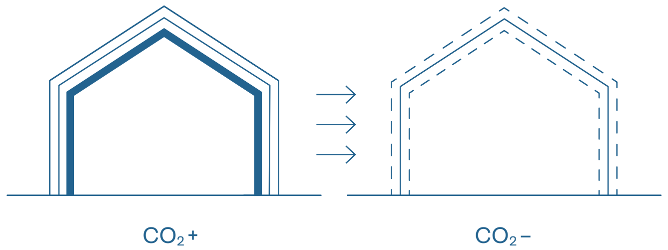


Balancing built and natural spaces

The challenge of urbanisation globally is to find forms of development that can exist in balance with natural ecosystems. In Ireland, the urgent need for new housing should be balanced against the maintenance of existing landscapes that have the potential to sequester and store carbon, such as forests, wetlands, or grasslands. The different residential typologies studied provide homes for communities at a wide range of densities, meaning they consume different amounts of land. This has an impact on valuable existing land resources that could otherwise be preserved for other uses such as natural amenity, parkland, or agriculture.

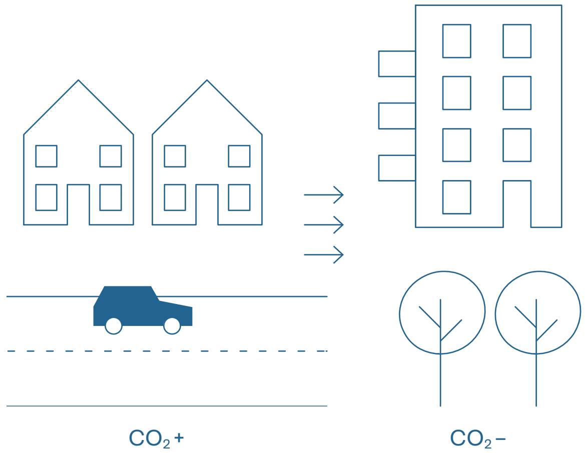
2



Carbon emissions of building materials

Certain building materials used in typical contemporary construction emerge as having a high embodied carbon impact, such as brick facades, concrete roof tiles, and insulation materials. Lower carbon alternatives could be easily be considered, for example concrete roof tiles could be replaced by slate or fibre cement, and insulation based on fossil fuel derivatives could be replaced by wood fibre, hemp, or other bio-based insulation products. The impact of concrete in structural elements such as foundations can be mitigated by the use of concrete containing low carbon cement based on recycled materials, such as Ground Granulated Blast-furnace Slag (GGBS).

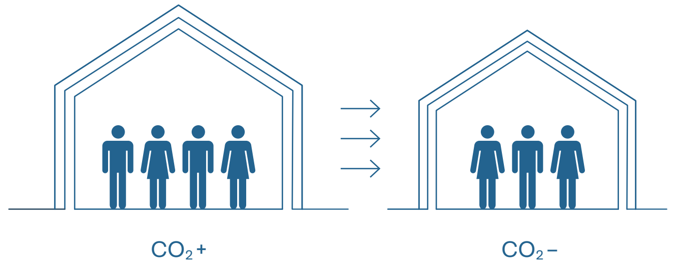
3



Carbon emissions outside the dwelling

Low-density housing types emit more embodied carbon per dwelling when external landscaping and road infrastructure are taken into account. This is partly due to the larger size of the dwellings, but is also due the extensive external surfaces and road infrastructure required to service them. Higher density apartment buildings are more carbon-intensive, but this is balanced by a more efficient use of external landscaping and infrastructure. The provision of vehicle infrastructure for new residential areas has a high embodied carbon impact, and the research finds that this needs to be considered along with the impact of the dwellings themselves.

4



Dwelling size and occupancy

The research shows that there is relatively little difference in the embodied carbon per square metre emitted during construction for different dwelling types, with timber frame houses having the lowest impact, and concrete frame apartments the highest. This finding is counterbalanced by CSO data showing large variation in dwelling size, with detached houses three times as large as apartments on average, resulting in a significantly higher embodied carbon. This effect is reinforced by 2022 census data showing that larger units with more bedrooms are less intensely used, with fewer inhabitants per bedroom. This could result in a higher embodied carbon per person.

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2 BACKGROUND TO THE RESEARCH

'Urbanisation should not be at the expense of rural development. In fact, both should be symbiotic and mutually enhancing'— World Cities Report 2020 The value of sustainable urbanisation [2]

Figure 2.11 From 'Unequal Scenes' by Johnny Miller

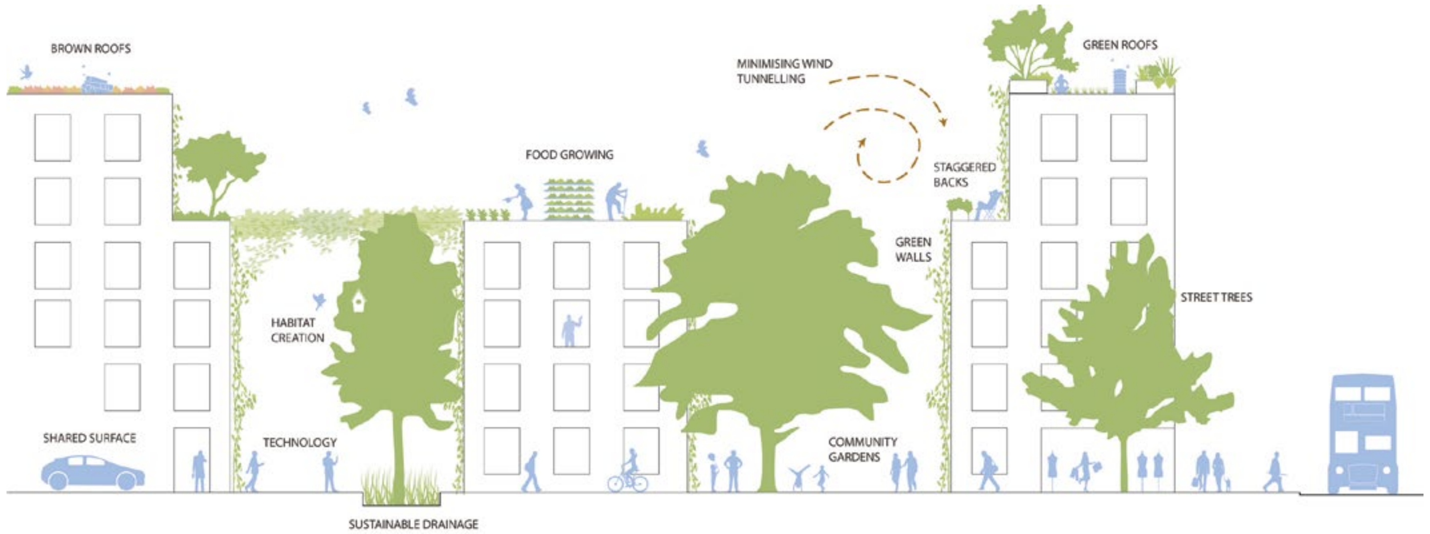


Figure 2.12 Wild West end Urban Greening Project, London.

2.1 Climate emergency and International Context

The provision of secure and sustainable housing is fundamental to the UN Sustainable Development Goals [3], yet allowing unplanned urban expansion and sprawl to meet housing needs eats into the world's natural resources, with profound implications for energy consumption, greenhouse gas emissions, climate change and environmental degradation. Over half of the world's population currently lives in cities, and this figure is set to rise to 70% by 2050. The rate of land consumption has significantly exceeded the rates of population growth over the last twenty years [4], due to the patterns and practices of unchecked urban expansion.

Developing new strategies for the provision of sustainable, climate resilient housing is therefore a pressing issue, and this involves more than reducing domestic energy demand and employing sustainable building practices. In order to imagine what sustainable housing will look like in the future we must expand the discussion outside of the individual dwelling and its energy consumption, to include its larger urban context and whole life impact on the natural environment. Responsible strategies of urban development will need to be prioritised, that use appropriate densities to maintain a balance with other land uses such as agriculture or landscapes of natural amenity such as forests and wetlands. Cities will need to expand by densifying within their existing footprints wherever possible in order to avoid impacting these landscapes.

In addition to responsible land use, cities need to incorporate the balancing effects of nature into the urban fabric through the use of nature-based solutions. These can take many forms including street trees, green roofs and green walls, landscaped amenity spaces and natural drainage systems (Fig. 2.12). When nature-based solutions are incorporated into the design of urban areas, these can create multiple ecosystem benefits, including carbon sequestration, temperature regulation, biodiversity increases, stormwater capture, and water and air purification. These solutions are part of a larger challenge to balance the impacts of carbon intensive urban development, with the carbon absorbing properties of natural landscapes. Sustainable housing typologies are ones that have the potential to accommodate these strategies.

2.2 Policy in Ireland: Housing Crisis, Climate crisis

In Ireland, an acute housing crisis has given rise to government targets for the production of approximately 50,000 new housing units per year [5], although this number has been questioned as too low to keep pace with current demographic trends [6]. These housing targets are also to be achieved in the context of drastic carbon emissions reductions across the construction sector by 2030, as part of the national Climate Action Plan [7]. Satisfying both of these targets will be challenging if we persist with business-as-usual scenarios where new housing demand is largely satisfied by construction on greenfield or peripheral urban sites. In addition to the embodied carbon emitted during construction demonstrated in this study, this type of development generates urban sprawl, and locks in car-dependant travel patterns associated with high carbon emissions.

Figure 2.31 whole Life carbon

The National Planning Framework 2040, specifically promotes policies of compact growth, targeting a high proportion of future housing development to be within and close to the existing footprint of built-up areas [1]. Such development may involve the re-use of vacant buildings or infill sites. Unless projects are part of a Special Development Zone (SDZ), or Local Area Plan (LAP), there is no detailed guidance for how to build at different densities. The Department of Housing, Local Government and Heritage (DHLGH) recently set out higher target densities for housing in different locations in their document 'Sustainable Residential Development and Compact Settlements Guidelines for Planning Authorities' [8]. The development guidance in this document refer to house types, not apartments, for which there is a separate set of standards. There is therefore no coordinated guidance for developers or local authorities on how to meet these higher density standards, and what implications different forms and typologies have for meeting sustainability and climate change targets. This study seeks to bridge this gap by considering the carbon implications of various dwelling types, in order to provide guidance linking these aspects of government policy.

2.3 Whole Life Carbon in the Built Environment

Until now, the carbon impact of new construction in Ireland has not been fully assessed, as current regulations only require the reporting of the operational energy used to run buildings. This is recorded through the Building Energy Rating (BER) system that provides an estimate of annual energy consumption. The Building Regulations also provide technical guidance and operational energy targets for elements of new construction. For most developments, the operational phases of a building's life cycle emit the most carbon, however other life cycle stages of embodied carbon, are currently not required for assessment (Fig. 2.31). The requirement to calculate whole life carbon

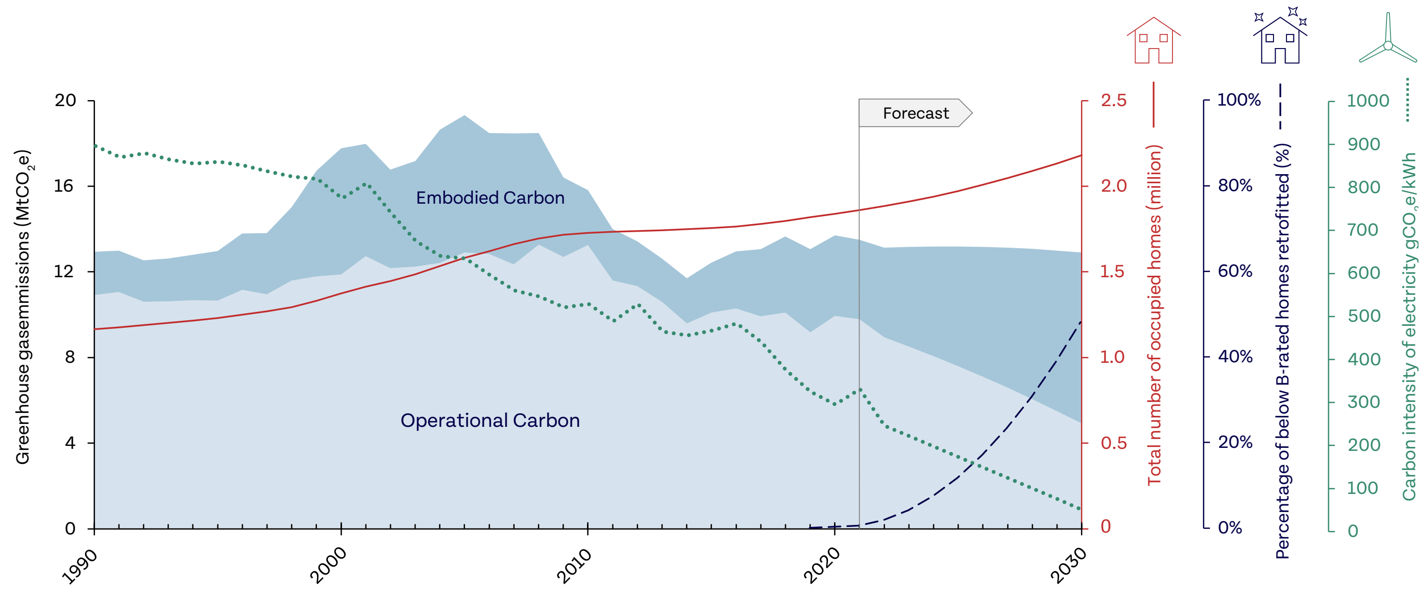


Figure 2.32 whole life carbon analysis of the Irish residential sector

of new construction forms part of the European Union's new Energy Performance of Buildings Directive, and will require the measurement of embodied carbon for all buildings over 1000m² by 2027, and all other buildings by 2030.

This situation is mirrored in the academic literature, where research to date has largely focused on the operational phases of whole life cycle emissions. The diagram above from the UCD project 'Whole Life Carbon in the Built Environment' (Fig. 2.32) shows that as the operational energy efficiency of buildings improves due to improved construction techniques and renewable energy measures, the impact of other life cycle stages that measure EC becomes proportionally greater [7]. In the forecasted scenario shown, the increased embodied carbon expended to meet housing targets will more than compensate for the savings due to improved thermal performance and increased use of renewable energy. Continuing on this trajectory will make it impossible to meet sectoral carbon reductions under the government's Climate Action Plan. Tackling the impact of embodied carbon in the production of new housing is therefore a matter of national urgency.

2.4 Housing and Land Use

Over recent decades, increasing numbers of people have moved to Irish cities, and this trend is projected to continue [9]. Housing provision for this new population has generally taken the form of low-rise suburban sprawl on peripheral or rural sites, carried out in piecemeal, discontinuous developments that are often dependant for access on the private car. In recent years new apartment construction has become more prevalent, however this has been dominated by the build-to-rent sector typically found in large developments in peripheral areas, or in isolated, hyper-dense clusters on urban sites. Apartments also provide a small percentage of the mix in large master-planned developments, that tend to be dominated by low-rise housing that is considered cheaper to build and easier to sell.

When urban regions expand as low-density suburbs, land is lost that could be maintained as natural amenity or used for agricultural purposes. The loss of this land can have potential knock-on impacts on biodiversity in addition to increasing greenhouse gas emissions [10]. Cultivating an understanding that land is a precious resource - and that urban

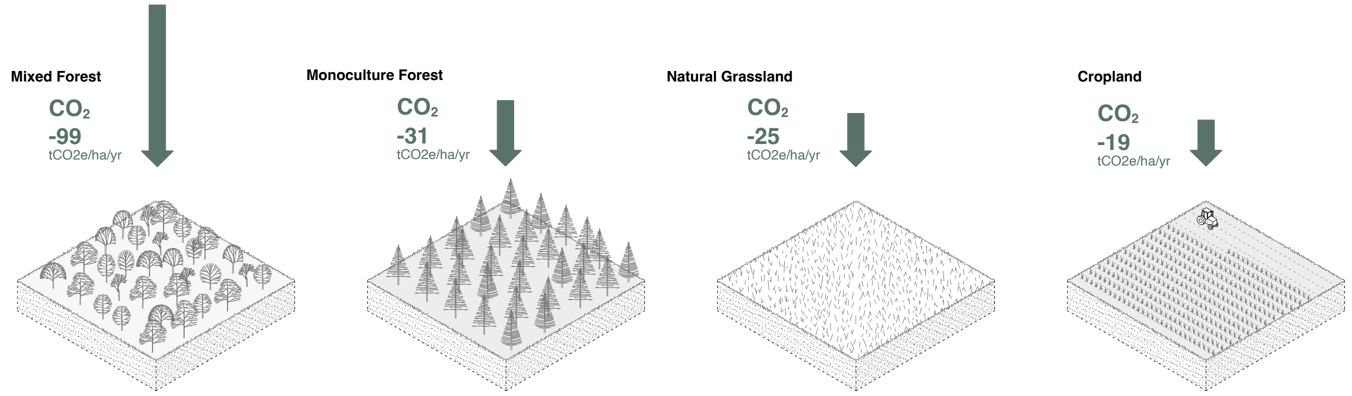


Figure 2.41. Carbon sequestration rates of one hectare of different landscape types. Data source: European Environment Agency

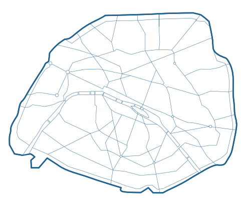
and natural environments need to be balanced - is critical as we transition to a low-carbon future. This is important even in a country like Ireland that has a large agricultural sector, and is sparsely populated by European standards. New housing therefore needs to be assessed against its impact on both existing and potential land uses, and density is a key consideration for this. By building compact settlements at higher densities, land could be freed up for intensive greenhouse-based agriculture that could then feed the local community, breaking the cycle whereby cities expand at the expense of agricultural land. Alternatively, building at higher densities or within existing urban footprints can maintain landscapes such as wetlands and forests that can sequester and store large quantities of CO_2 [11].

2.5 Scope of Study: Dublin Context

The chosen study area comprises County Dublin, which consists of four Local Authorities: Dublin City Council, Fingal County Council, Dun Laoghaire Rathdown-County Council, and South Dublin County Council (Fig. 2.51). This scope of study was chosen as it lies within the commuting hinterland of Dublin, and includes a wide range of housing types and densities, from one-off rural housing, to newly-constructed estates, to hyper-dense housing on urban infill sites. While much of the County Dublin is already built on, there are also large vacant sites, under-used brownfield sites, and land banks zoned for housing. This unbuilt potential confirms the importance ensuring that future development is carried out in a sustainable manner.

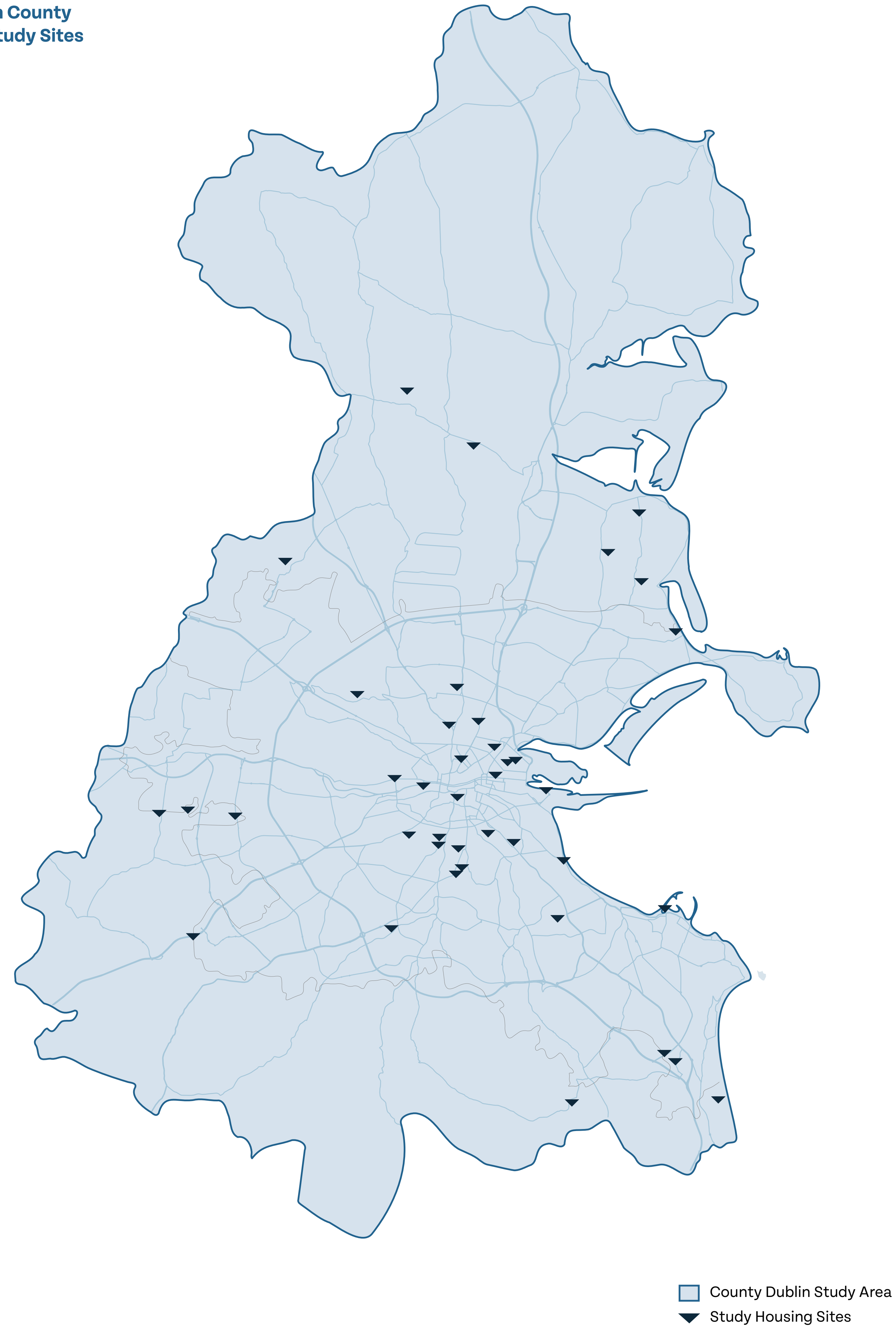
This availability of land is in contrast with the widespread perception that Dublin is heavily built up, and that there is no space for development without expanding the city outwards through sprawl, or upwards through taller developments. Although building taller in certain locations can make sense - for example providing dense clusters close to public transport nodes and centres of employment - Dublin's relatively low population density suggests that raising heights as an overall strategy to provide housing is not required. The diagram shown in figure 2.52 compares the population density of central Dublin (Dublin City Council area) with that of Paris, showing that there are approximately five times more people living in each square kilometre of Paris compared to the same area in Dublin. Although Paris is exceptionally dense by European standards, tall buildings of eight storeys or more are not allowed in central zones. From a sustainability perspective tall buildings also require careful consideration, as research shows that buildings of six storeys and above become carbon intensive to construct largely due to heavier structural requirements [12].

Dubin City Council Area Population: 592,713
Area: 118 km²
Density: 5032 persons/km²



Paris City Centre Population: 2,048,472
Area: 105 km²
Density: 19,509 persons/km²

Figure 2.51
Dublin County and Study Sites



3 HOUSING TYPOLOGIES IN IRELAND

3.1 Dublin: A Brief History of Housing Typologies

Compared to the European average, relatively few Irish people live in purpose-built apartments – approximately 15% compared to an EU average of 40%. In Dublin, despite being the country's largest urban centre, just over ten percent of the population live in apartments [CSO Table FY033A]. To uncover some of the reasons for this, it is useful to briefly consider the particular history of Dublin, a city that a hundred years ago had some of the worst tenements and housing conditions in Europe. The political reaction to this was an ambitious slum clearance project begun in the 1930s, which took two main forms [13]: extensive urban flat building projects (Fig 3.1), and suburban developments loosely based on English ideas of the Garden City, in schemes such as those constructed at Cabra and Crumlin-Drimnagh (Fig 3.2). Following the recommendations of the Housing Inquiry report of 1939, it became clear that the preferred policy response to the tenement problem was to build suburban houses and cottages instead of inner-city flats. This was partly due to the lower cost of suburban dwellings on virgin sites compared to flat developments on brownfield land. The report also deemed city centre living as too cramped to provide for healthy and salubrious family life. Soon, a division could be seen whereby flat typologies were seen as a suitable re-housing solution only for the poorest of the poor who could not relocate as they needed to be close to sources of employment. The suburban house type, by contrast, offered a chance for a new life and re-invention for those who could embrace it, and the individual house on a single plot became the dominant housing model [13]. This model was taken up by the Public Utility Societies, semi-private developers operating with state assistance, who built spacious low-density suburban estates in areas such as Glasnevin, Drumcondra, and Clontarf [14]. During the 1970s and 1980s, this pattern continued as private developers became the dominant housing providers, and the period saw a thinning out of the city centre and a rapid increase in suburbanisation that has been attributed to increasing patterns of home ownership [15]. In urban areas, the distrust that the tenements had originally inspired was transferred to

Top: Figure 3.11 Hanover Street Flats, designed by Herbert Simms, 1934-1935

Above: Figure 3.12 Newly occupied houses in Marino, c. 1926

social housing in urban flat blocks, as these began to struggle with social and maintenance issues in the post-war decades. During this period, apartment living never achieved widespread adoption by private developers as a model for middle-class living, apart from occasional schemes such as the Mespil House Flats in the 1950s [16]. It is not unreasonable to speculate that the low cultural acceptance of apartment living that persists in Ireland to this day dates back to these historically-engrained attitudes, although poor standards of construction and inadequate space provision have also undoubtedly played a part.

3.2 CSO Data

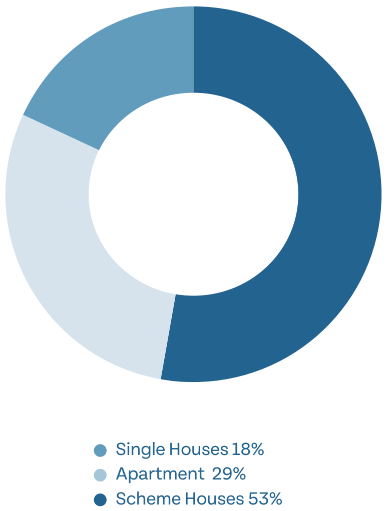
Dramatic differences in the space provision of housing types can be seen in the data from the last one hundred years, which show the size of individual detached houses generally rising, while apartment sizes remain largely static (Fig. 3.21). Moving to the present day the characteristics of the three dominant types in contemporary Irish housing production are classified according to the CSO new dwellings completion data for 2024 (CSO table NDA08), as comprising 18% single houses, 53% scheme or estate housing, and 29% apartments (Fig. 3.22) [17].

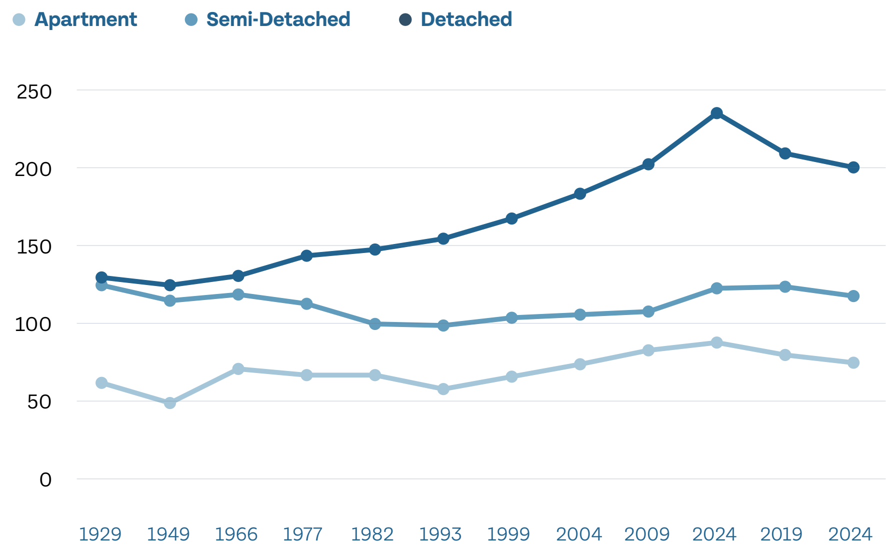
As part of this study a fourth category called low-rise medium-density has been added, which although less common in Ireland could become an important part of future strategies for sustainable urban development. The characteristics of each of the typologies chosen for analysis are briefly outlined in the following section.

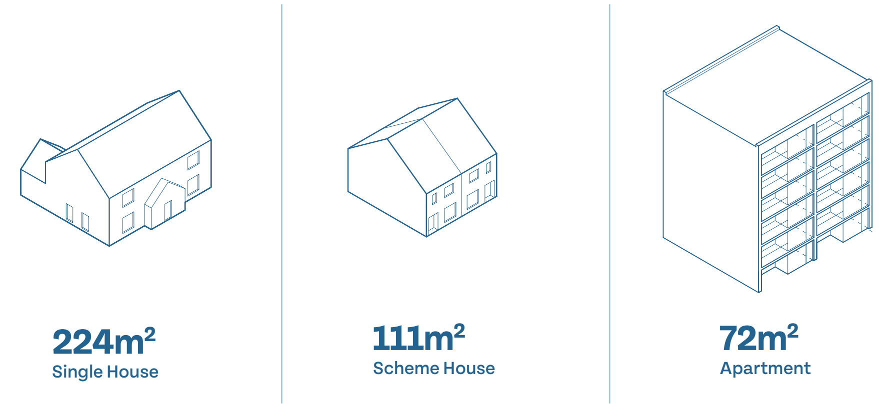
Below: Figure 3.22 Average new dwelling sizes by type 2024

Below right: Figure 3.21 Floor area sizes by housing type

Bottom: Figure 3.23 Average new dwelling sizes by type 2024



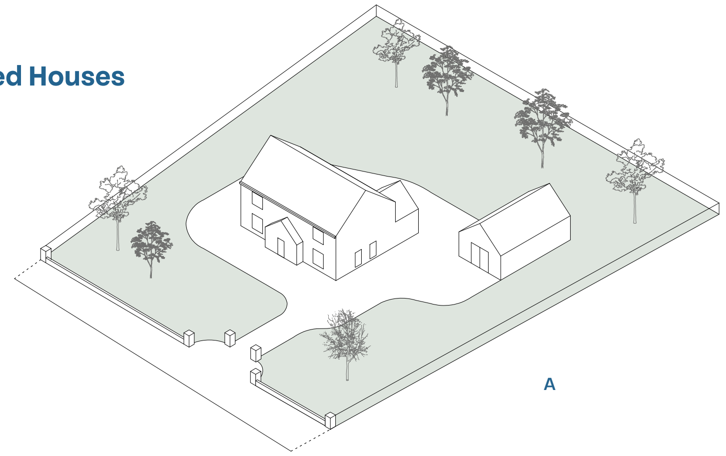




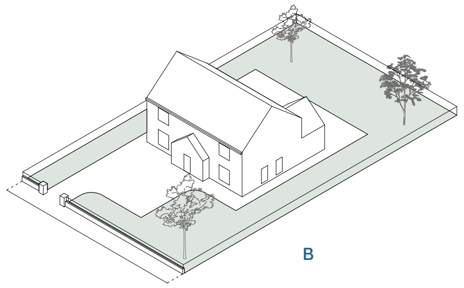
Left: Figure 3.31
Detached house:
one-off rural type

Below: Figure 3.32
A: Detached House
one-off rural type
B: Detached estate
house

3.3 Detached Houses



A



B

According to CSO data single houses represented 17% of all houses completed nationally in 2024. The primary sources for these data are ESB domestic supply connections, used as an indicator of housing completions. Single houses are the largest type in terms of floor area, at an average of 224m² for the year 2024. This is approximately three times the size of an average apartment constructed in that year. It is reasonable to assume that as these are farm houses or dwellings with an individual ESB connection, that they are also physically detached. For this reason, the term 'detached houses' is used for the rest of this report, although some of detached house types may not be classified as single houses by the CSO.

Detached houses show a much large variation in form and average size compared to commercial housing types such as estate houses and apartments, which conform to a narrower range of typologies due to commercial and regulatory constraints. The size of the plot on which a detached house will sit may also vary considerably, depending on its location and intended inhabitants. The detached houses considered in this study fall into three categories:

1. One Off Rural Houses
These are defined as houses with their own septic tank system and generally sit on a relatively large plot of land of an acre (approximately 0.4 hectares) or more. There are relatively few of these being constructed in the Dublin Local Authority areas, although some new detached dwellings are still being built in Fingal and Dun Laoghaire Rathdown (Fig. 3.32 A).

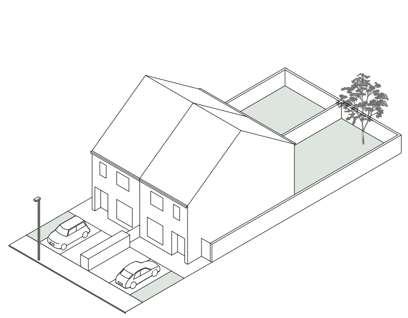
2. One Off Infill Houses
These are houses on brownfield sites in urban or suburban areas, either commissioned by clients, or constructed individually by builders for sale on the private market. They are often found on side and corner gardens or back-land plots, or they might be mews houses to the rear of longer dwelling plots. These houses tend to sit on smaller plots of land and are relatively few in number due to the scarcity of suitable sites.

3. Detached Estate Houses
These are individual dwellings constructed as part of larger estates, and as such are classed as estate houses, not single houses by the CSO. They are less common than terraced or semi-detached dwellings as they require more space, and developers seek to maximise the number of dwellings on a site due to high land prices and requirements to achieve minimum densities. They tend to be larger dwelling types with at least four bedrooms, and are often targeted at luxury end of the market. Despite generous internal space provision, these houses often have smaller gardens due to site constraints.

Left: Figure 3.41
Semi-detached houses

Below: Figure 3.42
A: Semi-Detached
Houses
B: terraced houses

3.4 Scheme Houses



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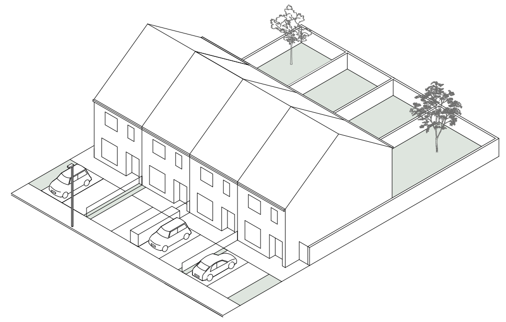


B

Classified as scheme houses by the CSO, housing estates remain the most common type of new residential construction, comprising 53% of national dwelling completions in 2024 (CSO table NDA08). This form of development often takes place on greenfield sites, and mostly consists of low-rise semi-detached and terraced housing (Fig. 3.42). In suburban or peripheral urban developments, it is common to see denser types such as duplexes and apartment buildings added to boost the overall density and meet planning requirements.

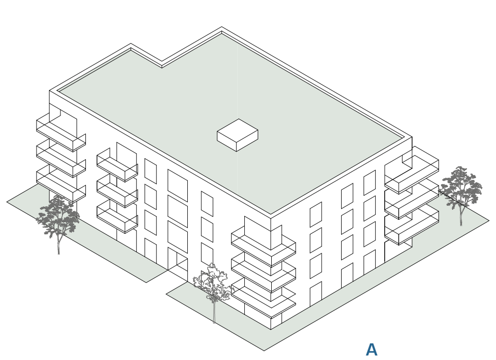
As can be seen from the studies comparing densities in the following section, estate housing requires a significant amount of road surface and parking area dedicated to vehicular traffic. In this type of development, it is common for the new roads and infrastructure to be initially constructed by the developer, and then later taken in charge by the Local Authority through a process set out in the Planning and Development Act.

It is important to briefly note that the planning context for housing estates has changed recently, with the publication of the government's 'Sustainable Compact Settlements - Guidelines for Planning Authorities', first issued as a draft in March 2023', and finalised in January 2024 [8]. This replaces the previous 2009 document 'Quality Housing for Sustainable Communities', and contains a number of changes to standards for houses, the most important of which is the reduction of the required distances between opposing windows to the rear of houses from 22m to 16m, with a consequent reduction in minimum back garden sizes. The result of this change is that the density of housing estates can be increased quite significantly. A further noteworthy change is a significant reduction in the requirement for car parking in urban areas or those close to public transport. Taken together these measures could result in overall increases in residential density, though it could be argued that this will be at the expense of residential amenity. This study analyses projects developed prior to these new regulations.

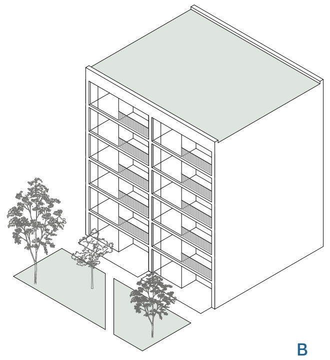
Left: Figure 3.51
Urban terraced apartments

Below: Figure 3.52
A: Suburban/ standalone aparments
B: Urban terraced apartments

3.5 Apartments



A



B

→

There were 30,330 dwellings completed in 2024, and apartments formed 29% of these. This figure has been rising significantly over the last number of years, particularly in the Dublin area. Of these apartments, 7,433 were social units according to government figures, indicating that the number of private units delivered was relatively low. This suggests a continued reluctance on the part of developers to build apartments, for reasons identified by the Society of Chartered Surveyors of Ireland (SCSI) which include weak market demand, the high cost of land, and high construction costs [18].

Any analysis of apartment buildings constructed by the private sector in recent years is complicated by the dominance of build-to-rent apartments, first included by the government in the Housing Guidelines of 2018, in an effort to encourage longer term rental arrangements managed by institutional landlords. Notionally aimed at a younger demographic, these units could have less storage and amenity space than a regular apartment, and did not have the same requirements for dual aspect, leading to much denser plans than would normally be permitted.

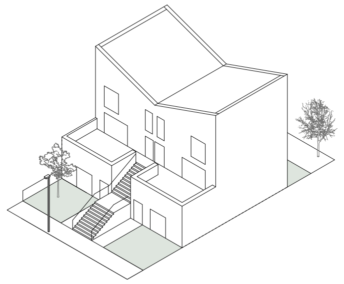
This made the build-to-rent type commercially attractive for developers, and led to an enormous number of build-to-rent schemes entering the planning system subsequent to 2018. Another factor in the proliferation of build-to-rent units was the overlapping Strategic Housing Development scheme, which allowed fast tracking of large residential development through the planning system. Many high-density schemes gained permission through this system, although to date a relatively low proportion of these has been built. The allowance of lower space standards for build-to-rent was ended in 2022, although it is set to continue as a form of tenure.

Build-to-rent has not been analysed in this study as it will not form part of the landscape of Irish housing production moving forward. It does however dominate the available data for private apartment developments in the planning system over the last few years. The apartments chosen for analysis are therefore a mix of social housing, private units in higher-end developments, and apartment blocks that form part of larger low-rise suburban estates. In the case of this last type, stand-alone apartment buildings are sometimes provided by developers in order to meet overall density requirements, and they are often allocated for transfer to Local Authorities as social housing units under the Part V planning provisions. The suburban apartment type shown in figure 3.52 A is generally a free -standing building with a single stair core and surface car-parking. The urban apartment type shown in figure 3.52 B can achieve higher densities as it can be connected to form longer terraces or courtyards. It does however require more stair cores in order meet development standards for dual aspect living, and is therefore more costly to construct.

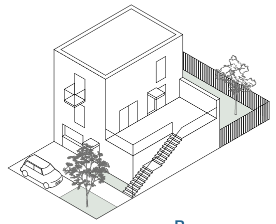
Left: Figure 3.61
Medium density townhouses

Below: Figure 3.62
A: Semi-detached Houses
B: Terraced houses

3.6 Low-rise Medium-density and the 'Missing Middle'



A



B

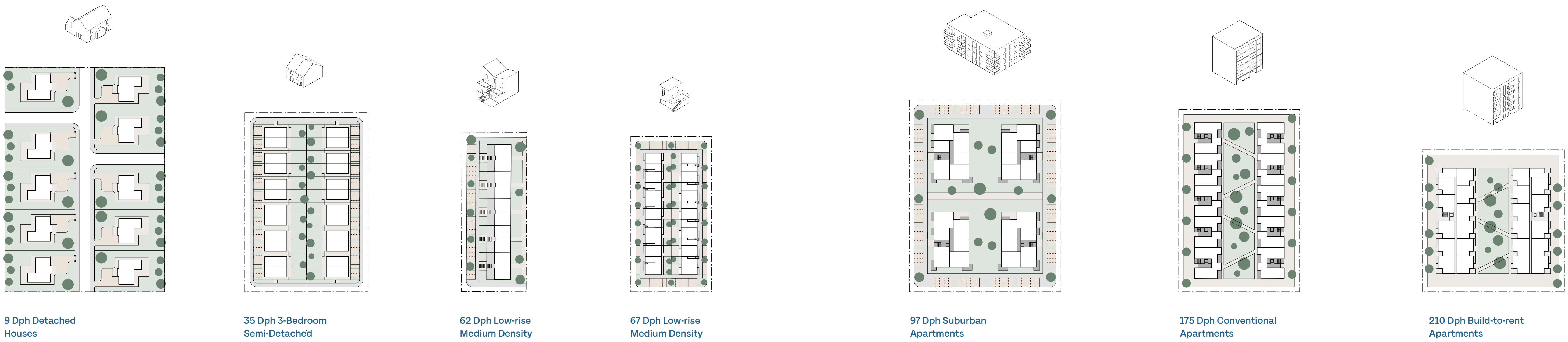
→

Although historically not common, low-rise medium-density housing typologies are becoming increasingly prevalent in Ireland, a trend that is set to continue under compact urban growth scenarios anticipated by the National Planning Framework [1]. Low-rise medium-density typologies can also be described by the umbrella term 'missing middle' housing, that originated in the United States to describe typologies that sit in between houses and apartments in terms of form and density [19]. These might be vertical townhouses with a small footprint and garden area, often incorporating higher level terraces or balconies. Other, denser types might stack one unit on top of another, with an independent staircase accessing the upper unit. This avoids the need for a common hallway, staircase, and lift, as required for apartments, thereby providing potential savings in space and construction costs. The omission of common areas also avoids the need for these to be independently managed, and this can be attractive to residents as well as to housing managers.

The most common low-rise medium-density housing typology in Ireland consists of a two -storey dwelling above a ground floor flat. Often referred to as a duplex, this typology effectively doubles the density that can be achieved on a conventional house plot, although it has certain practical disadvantages such as the requirement to provide a bulky staircase for disabled access, and the fact that the lower unit is overlooked by the one above (Fig. 3.62 A). Other possible typologies provide a first-floor terrace for the upper unit, which can be accessed from the street and provides a private amenity space to the upper unit (Fig. 3.6.2 B). This type has proved popular in the United Kingdom as an alternative approach to apartments for achieving higher densities on urban sites. While generally two or three storeys tall, a limit of four storeys is possible within Irish Building Regulations by stacking two duplexes one on top of the other. Beyond this height a lift is required, and apartment typologies with lifts are needed to deliver higher densities.

Low-rise medium-density housing typologies can provide a useful bridge in scale between the suburban houses that predominate in our towns and cities, and taller, denser apartment buildings that may be required in new developments. These typologies are generally compact in form, and efficient in density and land use. They form a useful part of the toolkit for sustainable urban development and compact growth.

Fig 3.71 Density Comparison of Typologies

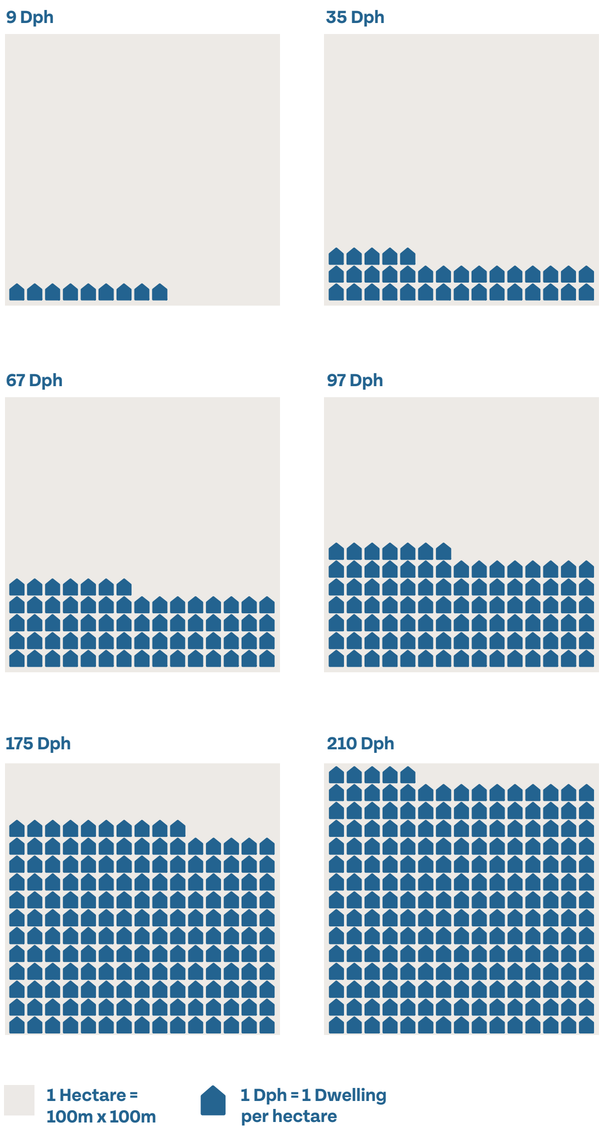


3.7 Density Comaparison of Typologies

Different dwelling typologies consume different amounts of land, and an extremely wide range of densities can be seen in figure 3.71, that compares the density of the various housing typologies under consideration. The site layouts shown are illustrative and are based on average conditions noted for different typologies following a study of recent planning applications in Dublin County whose location is shown on page 13. The dotted lines indicate the centre lines of roadways. The methodology for defining the site layouts is described in greater detail in section 4.2. The typical densities found range from 9 dwellings per hectare (dph) for detached houses – here shown as part of an estate layout – to 200 dph or more for build-to-rent housing. This range of densities is also illustrated graphically in figure 3.72, that shows the number of dwellings that can fit inside one hectare.

Note that the figures shown measure net density that includes all streets, gardens, and open areas directly associated with dwellings. The Government's recently published 'Sustainable Residential Development and Compact Settlements Guidelines for Planning Authorities' measures net density in a slightly different way as it includes common amenity spaces, landscaped areas and parks [8]. These public areas have been excluded from figure 3.71 as they vary in size depending on context, and there are different requirements for open space due to the different sets of Government guidelines for houses and for apartments. It should also be noted that the various typologies distribute common and private space in different ways. Houses have private amenity areas included within their curtilage as gardens, but require public open areas to be provided off site. Apartments have smaller private amenity spaces in the form of balconies and terraces, but their common amenity space can generally be accommodated on site in the form of courtyards and external landscaped areas.

Fig 3.72 Comparison of densities in one hectare

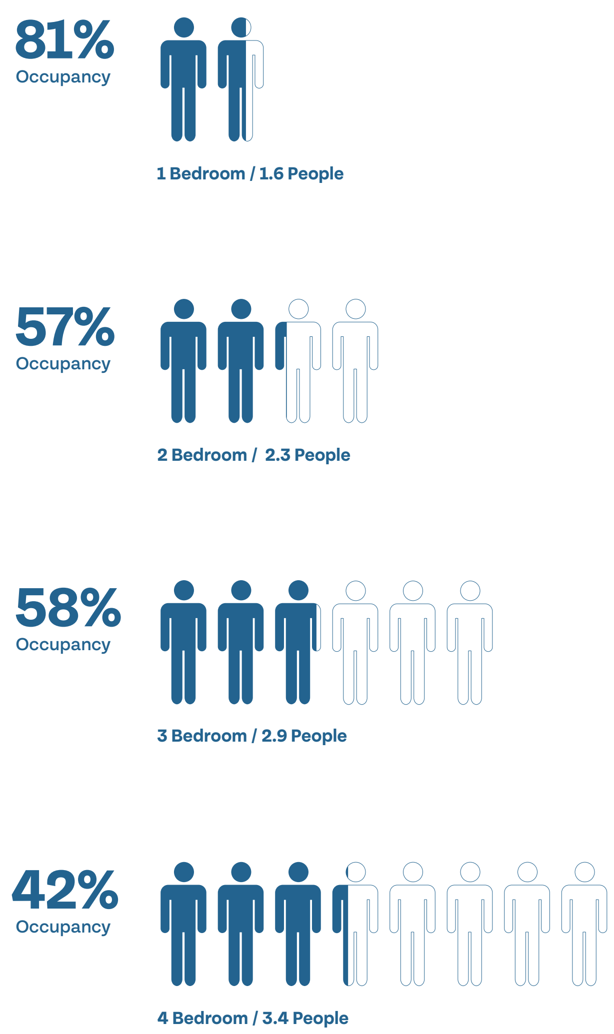


3.8 Density and Occupancy

This research measures density according to the standard metric of dwellings per hectare (dph), however a limitation of this metric is that it does not consider the type of dwelling or overall number of persons housed. A four-bedroom, eight-person house and one-bedroom, two-person apartment both count as one dwelling, but have different numbers of bedspaces. Furthermore, these dwellings might have different levels of occupancy, so the number of bedspaces does not necessarily tell us how many people are living in a given dwelling, and whether the space is used efficiently or not. For the first time Census 2022 asked respondents how many bedrooms they have, and this gives an insight into the rates of occupation of different dwelling sizes. Measured at the scale of the Dublin Region – the same scope as this research study – the census data show that smaller dwellings are more intensely occupied, and that rates of occupation decrease with a greater number of bedrooms (Fig. 3.81).

The census data provides a snapshot of how people occupy existing dwellings at a particular moment in time, although different patterns of occupation may be seen if newly-built dwellings only were measured. When considered together with the CSO data on dwelling size, we see that there is a wide disparity of space allocation across households, with some people enjoying plenty of space, and others very little. The amount of space allocated for each inhabitant is an important indicator for both housing quality and environmental performance, and there is potentially a tension between improving space standards and reducing carbon emissions, as EC increases according to the amount of floor area constructed. This is suggested by European studies that have shown a substantial difference between per metre squared versus per capita consumption of embodied carbon, with efficiencies in energy use per square metre being negated by larger space consumption [20].

Fig 3.81 Housing occupancy rates by number of bedroom for County Dublin



4 METHODOLOGY

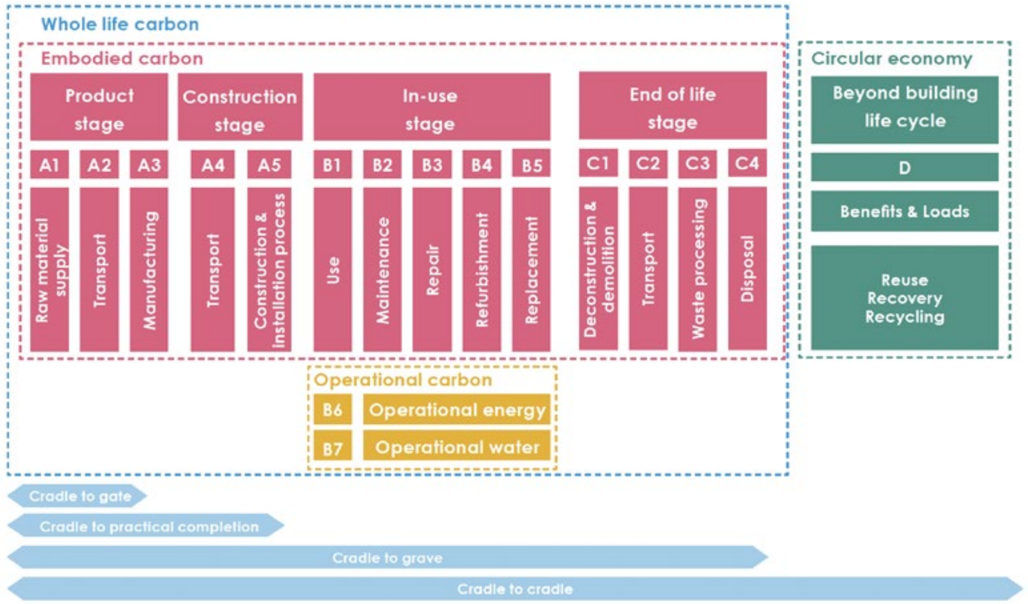
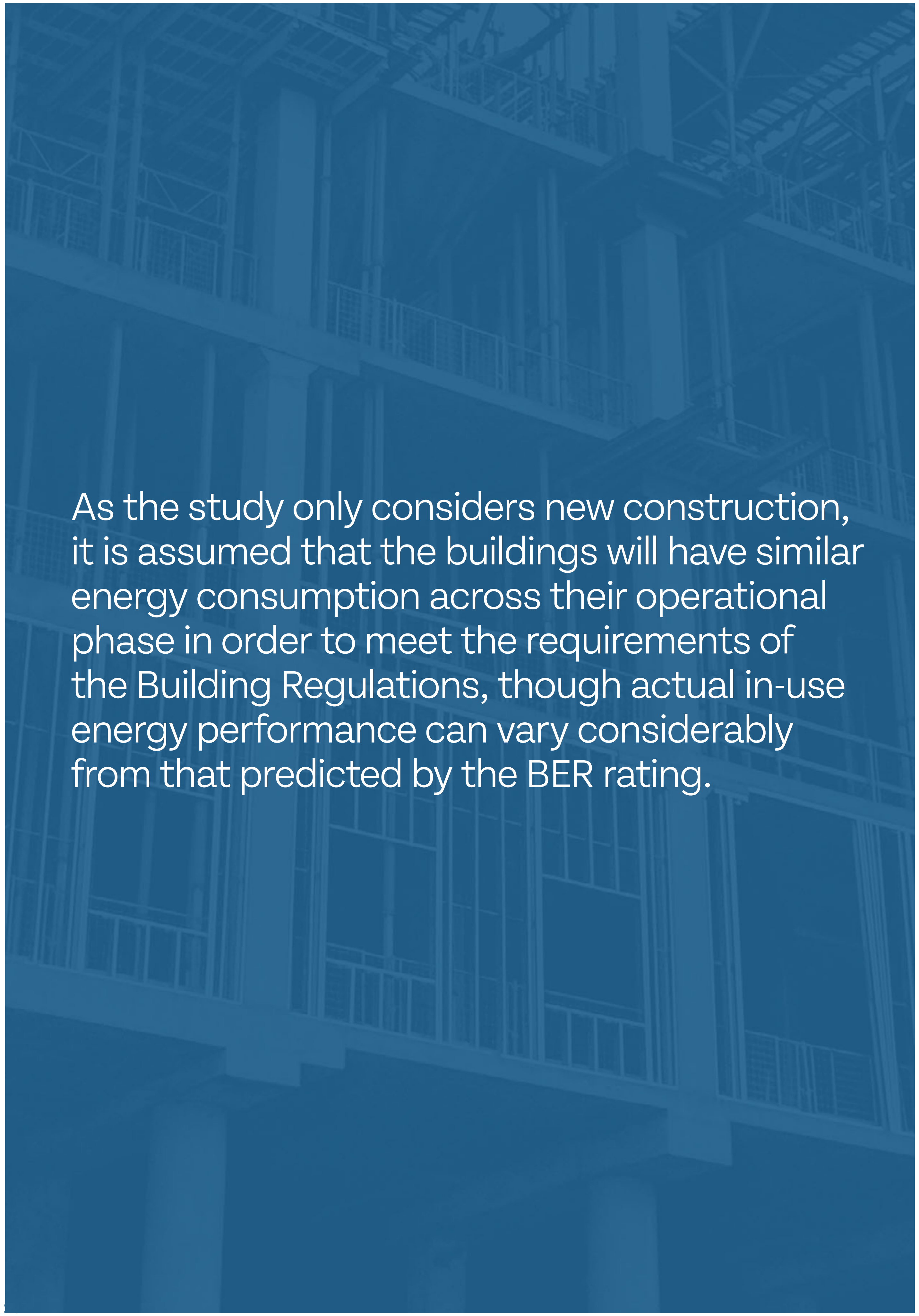


Figure 4.11 System boundary for life cycle assessment according to EN 15978.

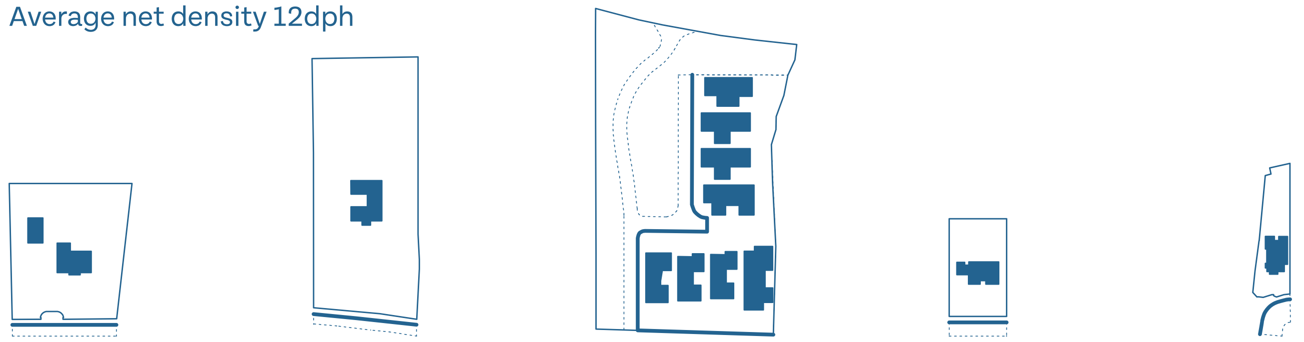
4.1 Embodied Carbon and Life Cycle Analysis (LCA)

The study investigates the upfront embodied carbon (EC) of residential construction created during construction phases. Embodied carbon forms part of the whole life cycle (WLC) carbon of a building, also known as a cradle to grave. This is the consideration of the carbon emissions of buildings, from manufacture of components and materials, through construction, operation and maintenance, until eventual demolition and possible recycling for other uses. These life cycle stages are shown in figure 4.11, with headings from A to D that track these life cycle impacts. Upfront EC is counted during life cycle stages A1-A5. The analysis of Whole Life Carbon is carried out in a Life Cycle Assessment (LCA), according to standards set out by EN 15978 [21]. The research has been carried out according to the EU Levels system Stage 2 'Detailed Design and Construction', a sustainability framework that assesses buildings across a fifty-year life span.

This study focusses on construction stages A1-A5 that are largest source of EC emissions. These stages include the manufacture of materials, their transport to site, and construction works. Insufficient data was available to allow for assessment of later stages, such as life cycle stage B6, operational energy. As the study only considers new construction, it is assumed that the buildings will have similar energy consumption across their operational phase in order to meet the requirements of the Building Regulations, though actual in-use energy performance can vary considerably from that predicted by the BER rating. It is also worth noting that in residential construction, life cycle stage B that deals with in-use carbon emissions can have a high contribution due to the energy demands of domestic heating systems and appliances, and the replacement cycles of plant and machinery such as heat pumps.



Detached Houses
Average net density 12dph



Single Dwelling
Site 2450m²
Floors 2
Road Frontage 42m
Net Density 4dph

Single Dwelling
Site 4304m²
Floors 2
Road Frontage 41m
Net Density 2dph

8 Dwellings
Site 8868m²
Floors 2
Road Frontage 187m
Net Density 19dph

Single Dwelling
Site 901m²
Floors 2
Road Frontage 23m
Net Density 11dph

Single Dwelling
Site 627m²
Floors 2
Road Frontage 21m
Net Density 16dph

Scheme Houses
Average net density 43dph

27 Dwellings
Site 6377m²
Floors 2
Road Frontage 322m
Net Density 37dph

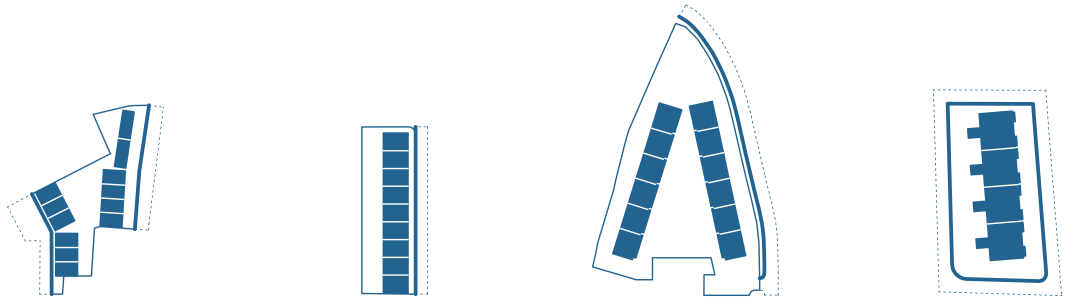
29 Dwellings
Site 6160m²
Floors 2
Road Frontage 315m
Net Density 41dph

21 Dwellings
Site 5202m²
Floors 2
Road Frontage 286m
Net Density 40dph

Figure 4.21 Planning data and urban morphology of the study

> Morphological characteristics of the sites studied include net and gross density, the size of site, and street frontage, which also indicates the amount of road infrastructure required to serve the development.

Medium-density Low-rise
Average net density 70dph



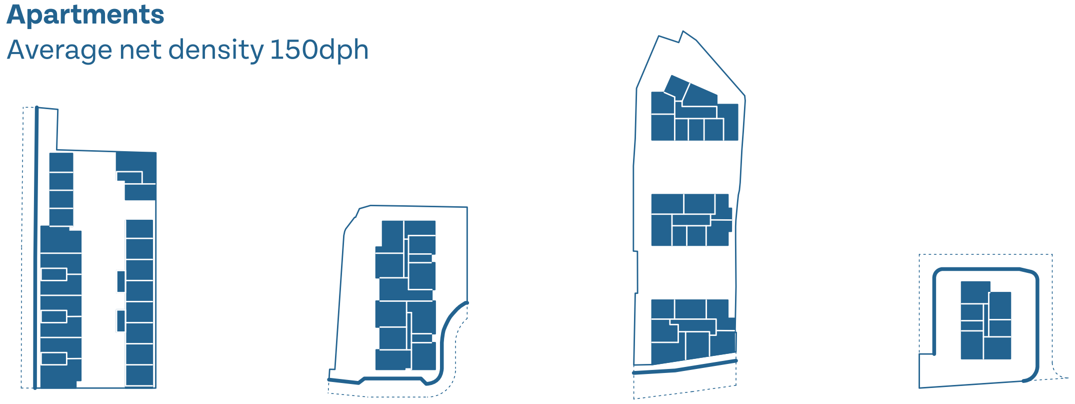
36 Apartments
Site 4460m²
Floors 3
Road Frontage 115m
Net Density 81dph

9 Dwellings
Site 1438m²
Floors 3
Road Frontage 67m
Net Density 63dph

12 Dwellings
Site 1638m²
Floors 2
Road Frontage 92m
Net Density 73dph

16 Dwellings
Site 2529m²
Floors 3
Road Frontage 253m
Net Density 63dph

Apartments
Average net density 150dph



91 Apartments
Site 4714m²
Floors 6–7 Over Basement Parking
Road Frontage 112
Net Density 193dph

39 Apartments
Site 3350m²
Floors 4 Over Basement Parking
Road Frontage 82m
Net Density 116dph

91 Apartments
Site 5030m²
Floors 5 Over Basement Parking
Road Frontage 41m
Net Density 180dph

22 Apartments
Site 1958m²
Floors 4
Road Frontage 187m
Net Density 112dph

4.2 Selection of Types for Analysis

In order to identify projects for whole life cycle carbon assessment, publicly available planning data was used to assess the three categories used by the CSO – single (detached) houses, scheme houses (estates), and apartments. As previously outlined in Section 3.0, a fourth typology of low-rise medium-density has been added. Using this data, residential developments were sifted and analysed first according to building typology and then according to planning data and urban morphology. Morphological characteristics of the sites studied include net and gross density, the size of site, and street frontage, which also indicates the amount of road infrastructure required to serve the development (Fig. 4.21). Following these basic categories used to define the scope, separate LCAs were carried out for buildings and external areas as explained in Figure 4.22. Having carried out the LCA for the external surfaces and road infrastructure, the final step in the methodology is to assess the proportion of this figure due to each dwelling typology. The processes of choosing the building typologies are first described, followed by the methodology for analysing their external areas and urban morphology.

Building Level LCA

External Level LCA

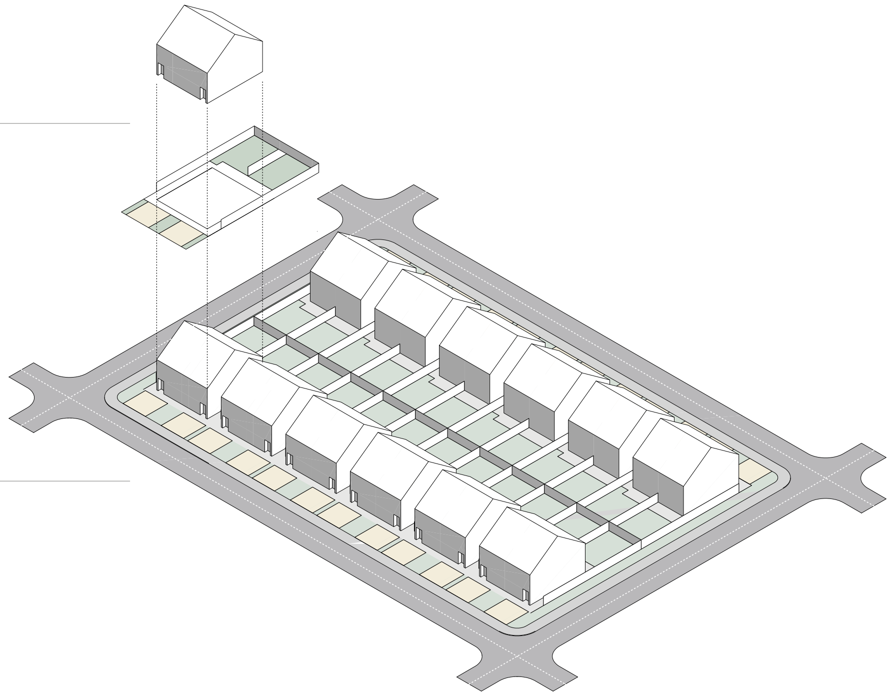


Figure 4.22 Separate data and urban morphology of the study typologies

4.3 Building Typologies

The four building typologies chosen for study are considered representative of current norms in Irish industry practice. As noted previously in Section 3.0, these norms can be clearly defined for the estate houses and apartments that are governed by clear sets of commercial and regulatory constraints. Detached houses exhibit much greater material and morphological diversity, so a detached dwelling of the CSO national average size has been analysed that uses a standard pitched roof form and typical construction materials for this type. The low-rise medium-density category includes a number of typologies as noted, so the study chose the most commonly found of these: a duplex dwelling consisting of a two-storey maisonette over a single storey flat.

4.4 External areas and Site Morphology

The process of whole life cycle analysis of the external areas needs to take account of the great variety of forms and site layouts that exist for residential development. Within the four chosen types, clear repeated patterns of site layout emerge, and these were used as the basis of the study. In order to determine these, first the range of morphological characteristics referred to above were measured for each type in order to determine average conditions. These were then used to construct an abstracted model of a typical site for embodied carbon analysis. This is done for illustrative reasons, as this process contains margin for error given that there was only scope to analyse a limited number of sites. Given the enormous differences in form and density noted previously between the types, this margin of error is held to be acceptable for a high-level study. For example, the apartments are more than ten times as dense as the detached houses, and the estate houses require more than ten times as much road infrastructure per dwelling than the apartments. The detached houses were not however included in the external LCA calculations, as these are too variable in their site layout and morphology for a single figure to be established, as was described in Section 3.3 previously.

The Life Cycle Assessment (LCA) methodology used is a tool called ‘Upfront’, developed by the Irish Green Building Council (IGBC) as part of INDICATE, an EU funded project to develop building-level data for WLC in Europe [22]. This tool is an Excel-based spreadsheet that contains material and carbon data specific to the Irish construction industry, with the intention that this data can also be used with commercially available tools such as One Click LCA, which is commonly used in Ireland and beyond. Upfront calculates WLC by construction element and life cycle stages according to standards set out in reference document EN 15978 [21]. Environmental Product Declarations (EPDs) have been used where available in order to estimate the global warming potential (GWP) of materials used. Where possible, EPDs used are from the Irish construction industry, or else the closest European equivalents are used. The Global Warming Potential (GWP) of other materials where no EPDs are available are calculated using carbon factors included in the Upfront tool, taken from the Inventory of Carbon and Energy (ICE) database managed by the University of Bath.

For the whole life cycle carbon assessment of buildings, case study projects were chosen that represent typical construction build-ups (refer also to appendix A). Where required, drawings were prepared in order to estimate the quantities of materials in each dwelling, and these quantities were then entered into a Bill of Quantities (BoQ), in preparation for carrying out the LCA.

For the external LCAs, drawings were prepared that estimated the surface areas of roadways, footpaths and external landscaping for each of the four typologies. A siteworks BoQ was then prepared that quantified these external surfaces in a form that could be used for the embodied carbon assessment. Typical construction build-ups of external surfaces were used for the LCA calculations.

4.6 Choice of Materials and Embodied Carbon

The choice of materials used for construction greatly affects the embodied carbon emissions of a dwelling. The Irish construction industry has traditionally used solid masonry products such as concrete and brick that are relatively carbon intensive. Switching to more sustainable materials and practices has been a slow process, and variations can be seen in construction materials depending on region and house type. In the Dublin area the volume house builders have almost entirely

Inertia to change can also be embedded in cultural and market-based norms of construction, such the expectation that a house appears ‘solid’ and is clad in masonry, or that roofs always need to be pitched.

switched to timber frame construction for estate developments, so this is the structural system that has been chosen for analysis in this study. These types of houses often a have conventional external appearance and their owners might not be aware that they have a timber frame structure. Inertia to change can also be embedded in cultural and market-based norms of construction, such the expectation that a house appears 'solid' and is clad in masonry, or that roofs always need to be pitched. While some of these can be practical responses to the Irish climate, this is not always the case as will be demonstrated later in the results section.

In this study, the most typical materials and construction systems in contemporary practice have been assumed for the purposes of analysing the different housing typologies (refer to appendix B). This inevitably throws up some anomalies, as the typologies are not being compared using like for like construction systems, for example the estate houses use a timber frame structure, whereas the apartments use reinforced concrete, which has higher EC per square metre. In general, the higher density types use more carbon intensive structure and materials due to the greater number of floors, and other requirements such as fire resistance. This may not need to be the case in future, as noted in section 6.0 that considers the decarbonisation opportunities offered by more sustainable materials and practices.

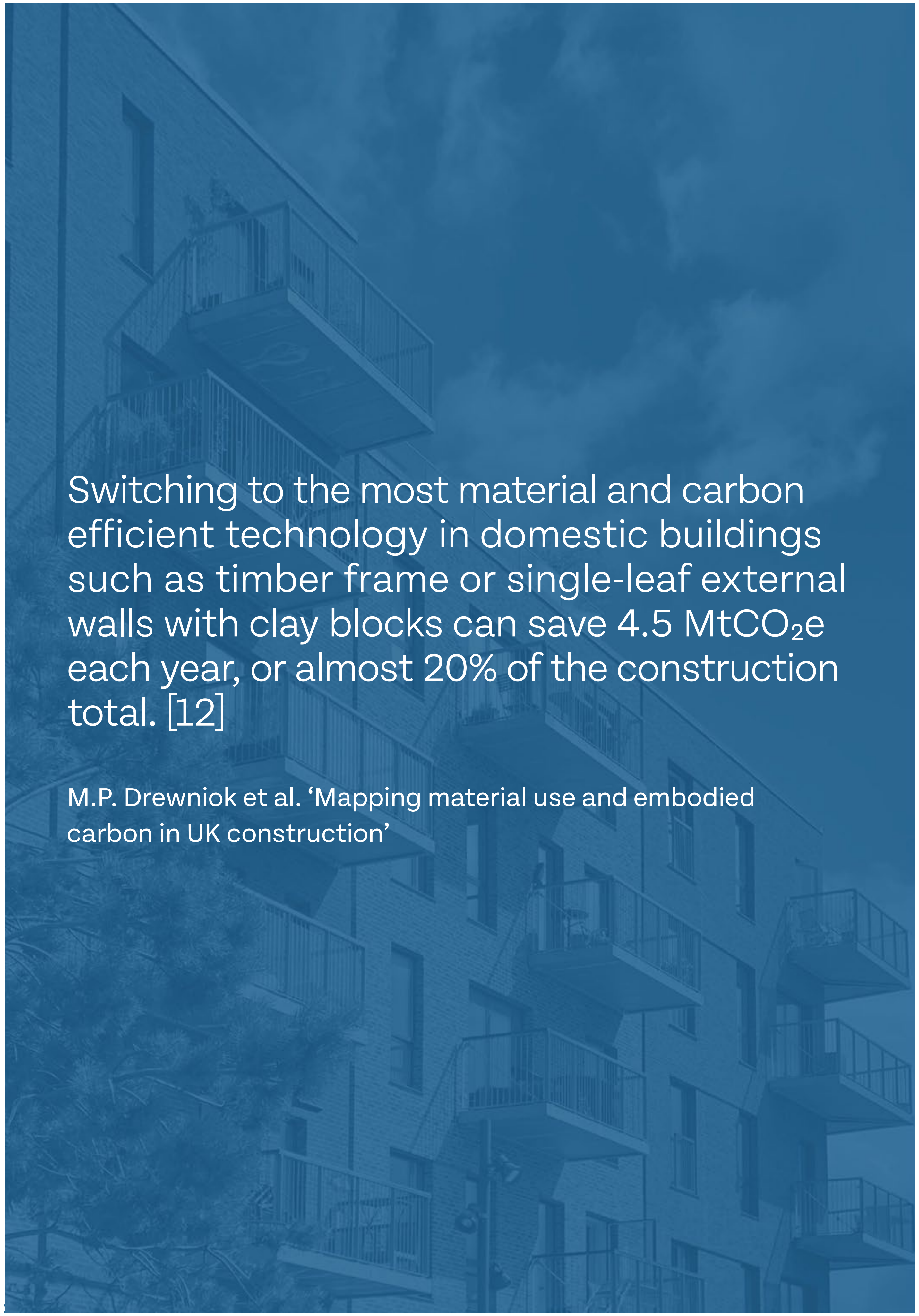
4.7 Limitations and Assumptions of the Study

Finding sufficient data to carry out detailed Life Cycle Assessments (LCA) proved difficult, and certain assumptions have been made as a result. In some cases where detailed drawings were not available, standard construction build-ups have been assumed that would be typical for that building type in Ireland.

It was not possible to obtain Mechanical and Electrical (M&E) services information for any of the projects so information based on similar residential projects has been used from studies carried out by the Chartered Institute of Building Surveyors in the UK (CIBSE) using their method for estimating the embodied carbon of services known as CIBSE TM65 [23].

The study of external areas has not included service infrastructures such as street lighting, buried utilities such as drainage pipework, and electricity and water supply. Detailed siteworks construction information would be needed in order to estimate these. Although services have not been included, it is worth noting that the road infrastructure measured in this study will provide an accurate proxy for many of these utilities, which are typically buried underneath roads (foul and surface water drainage), or footpaths (water, lighting ducts, and electrical supply).

The site plans analysed have been abstracted to describe the best approximation of typical variables derived from the real-world examples studied previously. These variables include density, plot ratios, and street frontage or length of road infrastructure. As the real-world examples contain a wide degree of physical variability, the abstracted site layouts are considered an approximation for illustrative purposes. This is in contrast to the typical building typologies which can be more precisely defined, with the exception of the detached houses which vary in form and size as noted previously.



Switching to the most material and carbon efficient technology in domestic buildings such as timber frame or single-leaf external walls with clay blocks can save 4.5 $MtCO_2e$ each year, or almost 20% of the construction total. [12]

M.P. Drewniok et al. 'Mapping material use and embodied carbon in UK construction'

5 RESULTS

Considerable Greenhouse Gas (GHG) emissions arising from the residential sector are attributable not only to residences in use (operational carbon), but also to their construction (embodied carbon). Viewed throughout Europe as a key sector for emission savings, national climate policy is often focused on reducing the operational energy of the residential sector, with little focus on the embodied emissions of its construction. [7]

R. O. Hegarty and O. Kinnane, 'A whole life carbon analysis of the Irish residential sector—past, present and future'.

Figure 5.01 Site preparation and earthworks on a construction site

Fig 5.02
Results Summary: Embodied Carbon Stages A1–A5

	Detached House 224m²	Semi-Detached House 118m²	Medium-Density Low-Rise 103m²	Apartment 93m²
Typology				
Embodied carbon m²	417 KgCo$_2$e/m²	349 KgCo$_2$e/m²	410 KgCo$_2$e/m²	445 KgCo$_2$e/m²
Embodied carbon per dwelling	93421 KgCo$_2$e	41211 KgCo$_2$e	42474 KgCo$_2$e	41289 KgCo$_2$e
Embodied carbon of external areas	N/A	7361 KgCo$_2$e	2402 KgCo$_2$e	1889 KgCo$_2$e
Total embodied carbon incl. external areas	N/A	49229 KgCo$_2$e	49229 KgCo$_2$e	24476 KgCo$_2$e

As outlined in section 4.3, an innovative aspect of this study is the inclusion of external areas such as roads and hard landscaping. The results first present the LCAs showing embodied carbon for the house type analysed. Following this, the breakdown of external public areas is shown. Finally, the two sets of results are combined, showing the impact that the external works have on the overall embodied carbon of the dwelling. A summary of the results is shown in figure 5.01 above, that shows first the EC per dwelling, and then the increase in this figure once the external areas are included.

Detached Houses

Fig. 5.11 Embodied Carbon by Construction Element

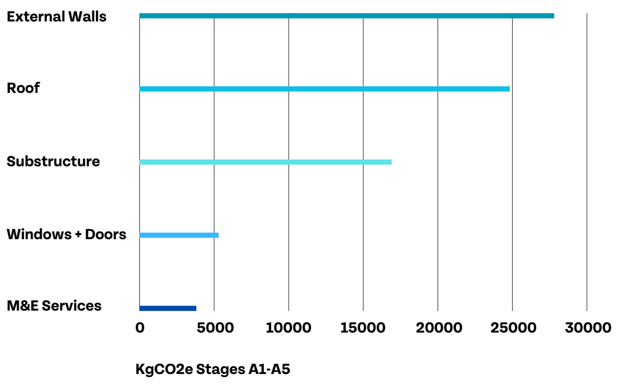
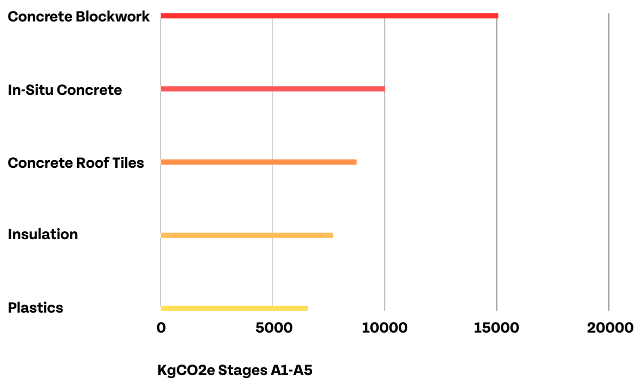


Fig. 5.12 Embodied Carbon by Material



External walls are the construction element with the highest impact in the detached house, and the highest impact materials are the concrete blockwork and cavity insulation that form these walls. This can be contrasted with the smaller estate dwellings, that show embodied carbon savings by the use of timber frame structure. Detached house types can also be constructed using timber frame, however in the examples studied this was rarely the case and cavity wall construction was more commonly used. A reason for this is that detached houses tend to be much larger than estate houses, and have bigger rooms requiring larger structural spans that are difficult to achieve with timber. Concrete roof tiles also stand out as a high carbon element. This is related to the use of pitched roof forms which create a large surface area of roof covering, and to the larger plan dimensions of this type of dwelling. Lower impact roof coverings such as slate or fibre cement could be used to reduce this figure.

Semi-Detached Houses

Fig. 5.13 Embodied Carbon by Construction Element

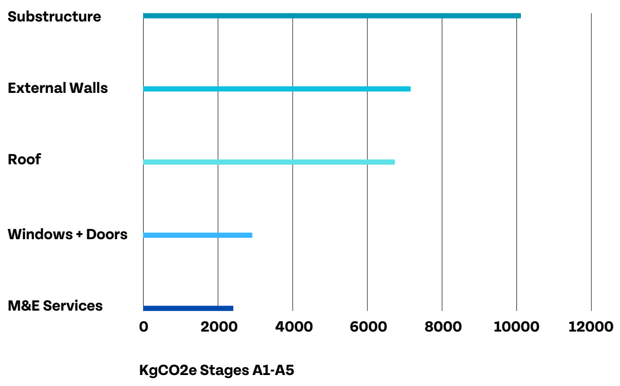
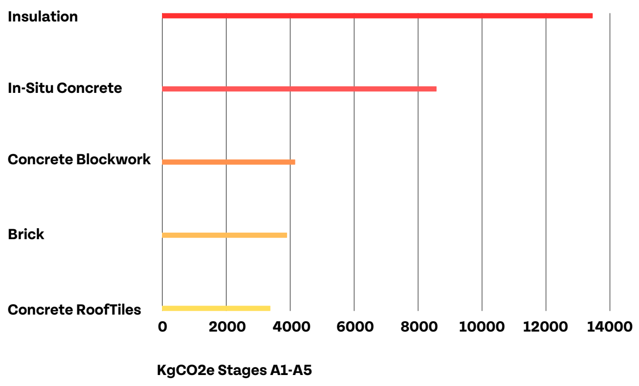


Fig. 5.14 Embodied Carbon by Material



The elemental and material breakdowns of the semi-detached house in Figures 5.13 & 5.14 show that significant carbon is expended in the substructure, roof, and external walls. Concrete is the most carbon intensive material, closely followed by insulation, which is mostly of the PIR type. The external walls are of timber frame structure, which is inherently low-carbon, however the buildings are finished externally in rendered concrete blockwork or brick, high carbon materials that are visible in the results. Reading these results, we could question the logic of cladding these timber frame buildings in rendered concrete block and brick, given the high relative contributions of these materials to the carbon count. The roof is also a significant source of carbon emissions, due to the concrete tiles commonly used, and the amount of material generally created by the large volume of the pitched structure. Other roof coverings such as fibre cement slates, or green roofs with a lower pitch, could be considered that would reduce the carbon impact of this element.

Reading these results, we could question the logic of cladding these timber frame buildings in rendered concrete block and brick, given the high relative contributions of these materials to the carbon count.

Duplex Dwelling

Fig. 5.15 Embodied Carbon by Construction Element

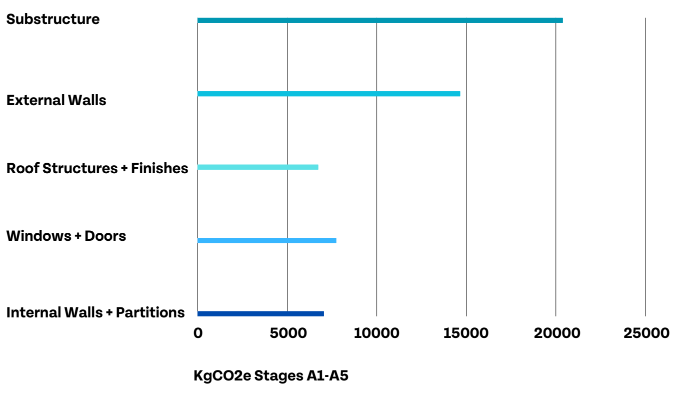
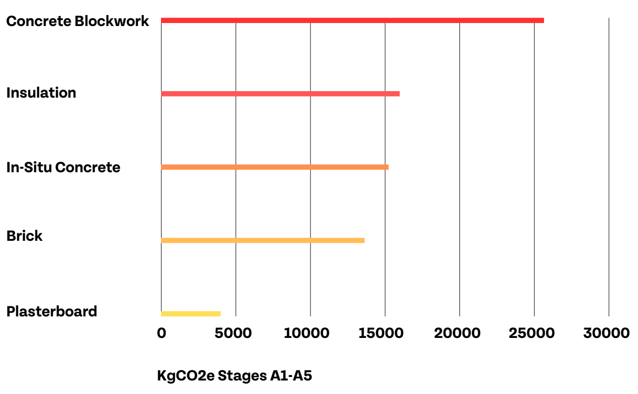


Fig. 5.16 Embodied Carbon by Material



The duplex dwelling has a higher A1-A5 embodied carbon figure than the standard low-rise estate house. This is to be expected as the ground floor unit and first floor slab of this building are of concrete construction, mainly due to the requirements for fire separation between the stacked units as required by the building regulations. These requirements are met by using concrete walls and slab instead of timber frame. Another contribution to the high external wall figure is the increased area of brickwork. The large external staircase is also a carbon hotspot, being formed from in-situ concrete. The large dimensions of these stairs are a requirement of Part M of the Building Regulations which requires access for the ambulant disabled to first floor dwelling such as this. Considering the modest contributions of the other materials, it is reasonable to assume that changing this building to timber frame would create significant carbon savings, if in future this could be safely certified under the Building Regulations.

Apartment Building

Fig. 5.17 Embodied Carbon by Construction Element

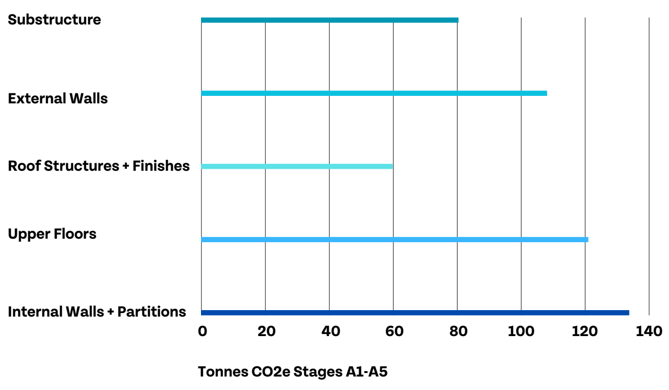
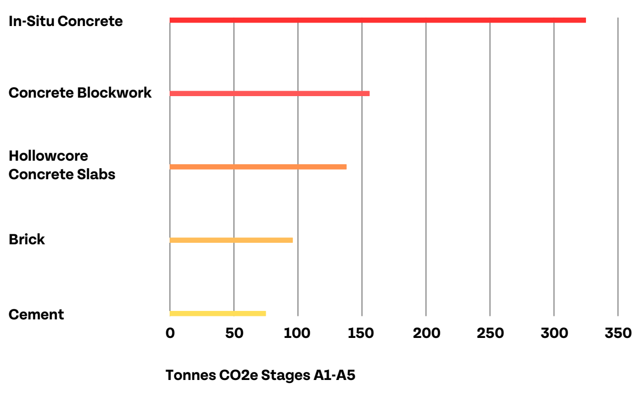


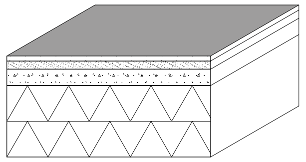
Fig. 5.18 Embodied Carbon by Material



Apartment buildings in Ireland generally have a concrete structure, and this shows up clearly in the diagram above, where concrete elements of different types are the highest impact materials (Fig. 5.18). The high figure for internal walls is mainly due to the separating party walls between dwellings constructed in concrete blockwork. The external wall also shows a high figure, but this could be particular to the suburban apartment block type studied, which has a relatively high area of façade for each unit. Other, denser apartment types use lower carbon build-ups such as metal framing systems with insulation between the studs, which would have a lower impact than the concrete structure. As with the duplex dwelling, brickwork is one of the highest carbon materials. Planning authorities will often require buildings to be clad in brick, particularly in urban areas, and rules such as these may need to be reconsidered as we transition to a low-carbon future.

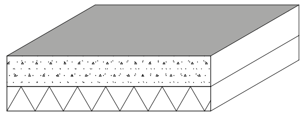
Planning authorities will often require buildings to be clad in brick, particularly in urban areas, and rules such as these may need to be reconsidered as we transition to a low-carbon future.

30
$KgCO_2e/m^2$



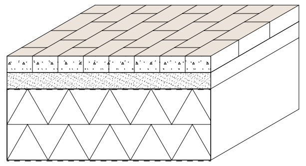
Asphalt Roadway
25mm Asphalt concrete–clause 912
40mm Binder course–clause 906
80mm Asphalt base course–clause 906
350mm Min aggregate–clause 808

81
$KgCO_2e/m^2$



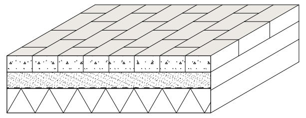
Concrete Foothpath
150mm Concrete 30N/20 on
150mm Min aggregate–clause 80
Note: Spec'd for vehicular traffic

41
$KgCO_2e/m^2$



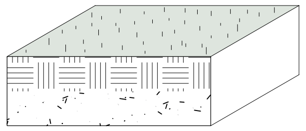
Permeable Concrete Paving
80mm Concrete paving slabs on
80mm Sand bedding
Geotextile membrane on
350mm Min aggregate–clause 808 on
Geotextile membrane

34
$KgCO_2e/m^2$



Concrete Paving
80mm Concrete paving slabs on
80mm Sand bedding
150mm Min aggregate–clause 808

+/-0
$KgCO_2e/m^2$



Grass Lawn
150mm Topsoil on existing subgrade
Note: Lawns can be carbon positive or negative depending on factors such as intensity of mowing and whether chemicals are used for maintenance

Figure 5.21 Embodied carbon of 1m² of external surface build-ups

5.2 Results of External Areas

In order to determine EC of external works, first LCA calculations were carried out of one square metre of typical external construction build-ups (Fig. 5.21). The square metre figures were then used to estimate the total external EC of the site layouts, and these are combined with the figures for the dwellings. The results for external works show that concrete footpaths and permeable paved parking areas have the highest EC impact, followed by roadways and pedestrian paved areas. Concrete footpaths represent a high overall figure as these are generally required to withstand vehicular traffic, and so have a robust and carbon-intensive construction. The parking surfaces are permeable as they form part of Sustainable Drainage Systems (SUDS), however the LCA results shows a high embodied carbon figure for these, mainly due to the concrete paviours and large quantity of crushed stone aggregate required. Despite their high EC impact, permeable parking areas could also provide sustainability benefits over the entire life cycle of a project, for example by absorbing surface water runoff which protects the public drainage system during periods of high rainfall. Permeable paved areas also reduce the amount of carbon-intensive drainage infrastructure required such as manholes and attenuation tanks. This is particularly the case if they can be combined with nature-based drainage solutions, as will briefly be discussed in Section 6.3.

Figure 5.22 External Works: $KgCO_2e$ EC per dwelling type

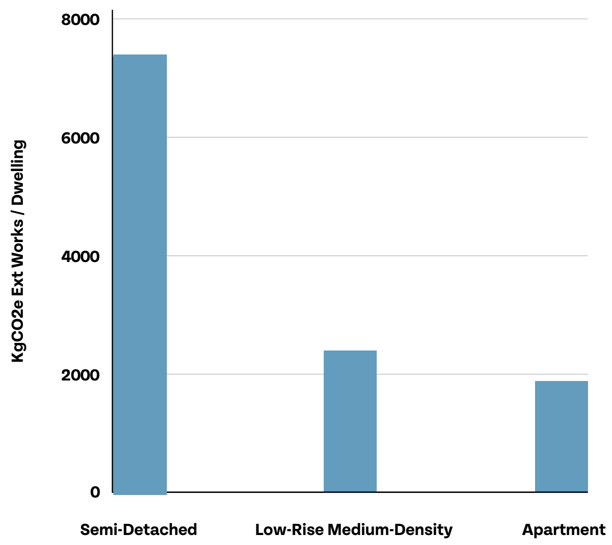
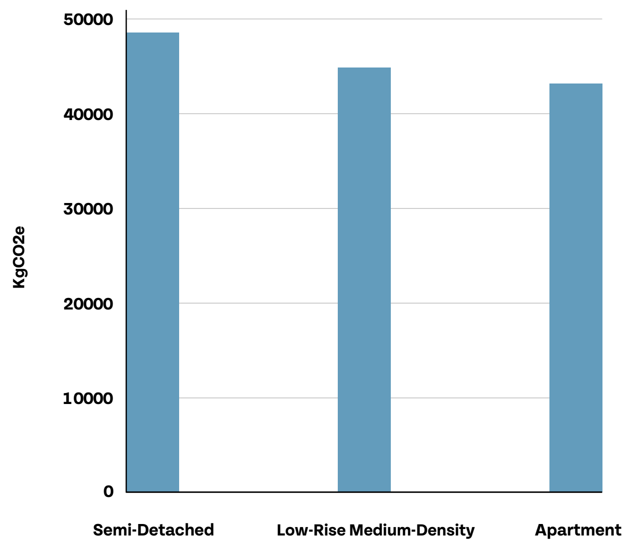


Figure 5.23 Total $KgCO_2e$ EC: External Works + Dwelling



5.3 Combined Results

The combined results demonstrate that hard-landscaped external areas and road infrastructure form a significant percentage of the total EC of residential construction, and that the proportion of this additional impact decreases with density. This ranges from 5% additional carbon due external areas and landscaping for the apartments, to 20% for the low-rise semi-detached houses (Fig. 5.22). Note that a similar additional figure has not been included for the detached houses, as these are too variable in their site layout and morphology for a single figure to be established, as can been seen in the site plans of these types studied in Section 4.4 previously. It can also be seen by looking at these site plans that significant quantities of infrastructure and landscaping are generally required to serve these dwellings. These results suggest that in order to carry out a holistic carbon assessment of new housing developments, the scope of LCA calculation should go beyond the dwellings themselves to include the entire site.

Dispersed dwelling patterns need to be connected through road infrastructure, and this results in higher EC emissions created by materials such as asphalt and concrete. Furthermore, the results suggest that these lower density forms of housing are inefficient in their use of land, occupying more area while accommodating fewer residents. Finally, although this study does not include transport-related emissions, inhabitants of the lower density types will require at least one car, resulting in tailpipe carbon emissions. In the other direction, the results show that the higher density typologies and urban morphologies are more efficient in their land use, and have lower emissions associated with their hard landscaping and road infrastructure. This suggests that there is an inverse relationship between increased residential density and reduced EC, although this is counterbalanced by the higher emissions associated with building structure as density increases. This counterbalancing of building and external results can be seen in figure 5.23. Combining the EC results of buildings and their siteworks can therefore support policies of higher densities and compact urban growth as described in the National Development Plan.

6 STRATEGIES FOR DECARBONISATION

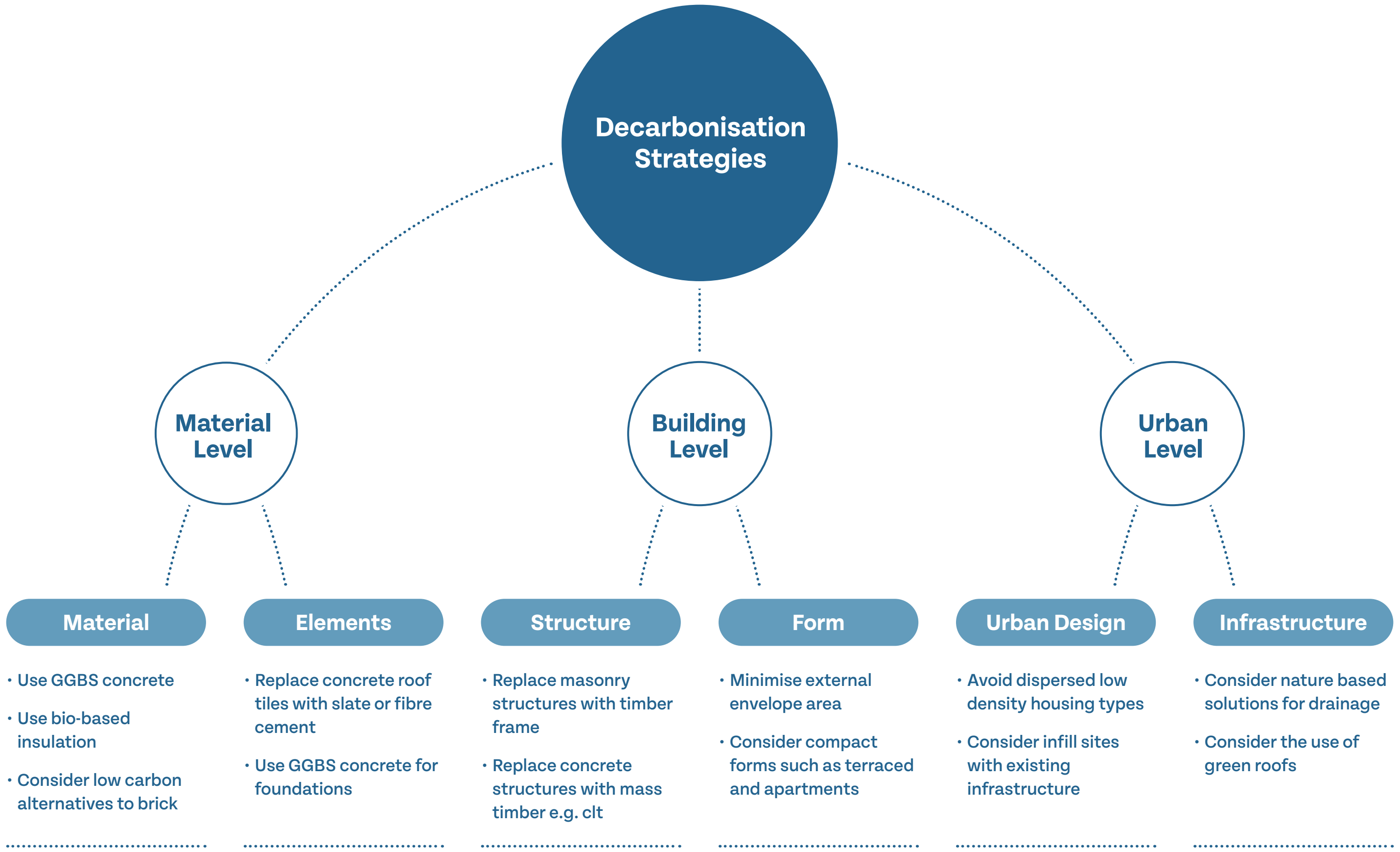


Figure 6.01 Diagram of decarbonisation strategies

The development scenarios described and measured in the previous sections make it clear that continuing with 'business-as-usual' practices will produce significant greenhouse gas emission, creating an urgent need to find alternative strategies. While it is beyond the scope of this research to provide quantitative analysis of such improved scenarios, the carbon studies of common housing types indicate obvious strategies for future decarbonisation. These strategies have been broken down into three different levels reflecting different scales of operation: Material, Building and Urban. These levels and strategies are summarised in figure 6.01 above. In each case, lessons are drawn from the results of this research as to how action can be taken to reduce overall built environment emissions.

6.1 Material level

A number of materials with a high EC impact occur across the four building types, such as concrete, brick, plastics, and petroleum-based insulation products. Many of these could be replaced with more sustainable versions of the same material, or substituted entirely with bio-based alternatives. Bio-based materials are any materials that are part of the biosphere sequestering carbon that is absorbed as the material grows. This carbon is then stored in the material and is not released into the biosphere at end of life if the material is recycled or disposed of sustainably. They tend to have good insulating properties. Some examples of such low or zero carbon materials are: hemp, sheep's wool, cellulose, wood fibre, cork, and mycelium (Fig. 6.10). These materials are still relatively uncommon in Ireland, but their widespread adoption would dramatically lower the carbon footprint of new construction. While in many cases they can be used as direct replacements for existing materials, there can also be issues of certification such as obtaining EU Agrément certs required for for new building materials and products that do not yet have a long history of use and for which published national standards do not yet exist. The Irish Green Building Council (IGBC) has called for the government to encourage the development of a national bio-based materials industry through financial incentives, or directly funding research and production facilities [24].

Figure 6.10 Bio based materials

Concrete

Concrete is known to be a polluting material, and is ubiquitous in the construction industry due to its low cost, strength, and versatility. Concrete often appears as one of the materials with the highest EC due to the sheer quantities with which it is used. In fact, when CO_2 emissions per kg of material are counted, concrete is not one of the most impactful common building materials. For example, standard red brick emits almost twice as much CO_2 per kg as concrete (0.12 kgCO_2e/kg for facing brick as opposed to 0.21 kgCO_2e/kg for 25/30 MPa in-situ concrete). Eliminating concrete entirely is difficult, as even the low-rise timber frame house types will still require concrete foundations. Stone foundations were common in vernacular Irish construction and these could be considered as low carbon alternatives for lightweight construction. Standard Portland cement used in concrete can be replaced with cement that uses recycled products such as those from the steel industry, known as Ground Granulated Blast-furnace Slag (GGBS). This can significantly reduce the embodied carbon emissions of concrete production, however concerns have been raised about the limited global availability of GGBS, and its ability to transform the concrete industry at scale [25].

Brick

Brick is a popular traditional material, and its use will often be required by planning authorities in public locations or onto street-facing facades. As noted above brick has a high carbon impact due to the temperature at which the clay is fired, and it appears as a significant source of EC emissions in the buildings studied here. Low-carbon masonry alternatives such as hempcrete are now available, or sheet materials such as timber or fibre cement could be considered as an alternative cladding. Recycled bricks can also be considered. A large number of brick buildings are demolished each year, and while hard sand cement mortars can make the reuse of bricks difficult, a percentage can generally be salvaged.

Insulation

The use of carbon efficient timber frame structures in the low-rise housing types studied is largely negated by the large quantities of insulation materials found that are fossil fuel generated, such as mineral wool based on stone or slag products melted at high temperature, or polyisocyanurate (PIR) boards based on petroleum extracts. Bio-based insulation products such as hemp, cellulose or sheep's wool insulation offer much lower embodied carbon from their manufacturing processes, in addition to sequestering carbon that is then stored in the organic material.

6.2 Building level

Materials used in the structural system have been generally found to account for over 50% of a building's embodied carbon [26]. Choosing an optimised structural system is therefore key to reducing emissions. Timber structures have been found to give savings of on average 68% compared to concrete [27]. Engineered timber such as cross-laminated timber (CLT) and Glulam have been used to provide solutions for housing across much of mainland Europe and North America. CLT comprises several layers of structural grade timber arranged crosswise and glued together, and is particularly well-suited to multi-storey taller wood construction. CLT is a CO_2 reservoir which means that carbon sequestered from the atmosphere during the growing phase is stored in the timber. According to Part B of the Irish building regulations dealing with fire safety, timber can only be used to construct buildings of up to 11 metres in height – a limit of three storeys. These regulations are at odds with construction practice in the rest of the EU, where CLT has been used for tall buildings of up to 20 storeys.

An alternative approach is to reconsider types of vernacular masonry construction, and systems of passive heating, cooling, and ventilation that traditional building techniques often demonstrate. The social housing project in Mallorca, Spain shown in figure 6.22, uses the traditional Mares sandstone masonry quarried on the island to provide thermal mass that cools the building in summer. The material also has a low embodied impact as it sequesters carbon and is quarried locally, reducing

> Bio-based insulation products such as hemp, cellulose or sheep's wool insulation offer much lower embodied carbon from their manufacturing processes, in addition to sequestering carbon that is then stored in the organic material.

Figure 6.21 Cross-laminated timber (CLT) housing, Dalston Works, London

construction-related transport emissions that are counted in life cycle stage A4. Favouring such local supply chains of materials and products is an important strategy for achieving a decarbonised construction industry. In an Irish context, existing stone quarries could be re-thought as potential sources of low-carbon structural and cladding materials.

Building form

The research has shown that compact building forms such as mid-terrace units, duplexes or apartment buildings are more energy efficient than detached or semi-detached forms, as they require less external envelope for the same floor area. This results in lower embodied carbon for a given floor area, as well as less heat loss during the building's life. The operational efficiencies of these denser typologies are counter-balanced by the fact that they require larger quantities of concrete or steel for their construction. As noted previously mass timber solutions such as CLT are not currently possible in Ireland due to requirements in the Building Regulations for non-combustible compartment floors over a height of 11m. If these regulations were to change, then the benefits of density could be achieved with low-carbon materials. An interesting area for future research would be to assess the impact of using timber construction across the different housing typologies, for example using timber frame for medium-density low-rise construction, and CLT for apartment buildings.

Height

While this study does not specifically focus on the relationship between number of storeys and the embodied carbon of residential typologies, a number of studies have found that embodied carbon per square metre tends to decrease with height. One UK study found that single storey detached dwellings are the least efficient, and that there is little difference in EC emissions between heights of two and six storeys [28]thus further increasing global greenhouse gases (GHG). After a height of between six

Figure 6.22 Social housing units, Mallorca, IBAVI

and eight floors, EC per square metre starts to increase, with high-rise structures also demonstrating decreased efficiency due to their need for larger structural elements, a greater number of lifts, and other servicing requirements. The necessity of building tall in order to meet housing targets was questioned in Section 2.5 previously, which argued that Dublin is not sufficiently dense for carbon-intensive tall buildings to be constructed at scale.

6.3 Urban Level

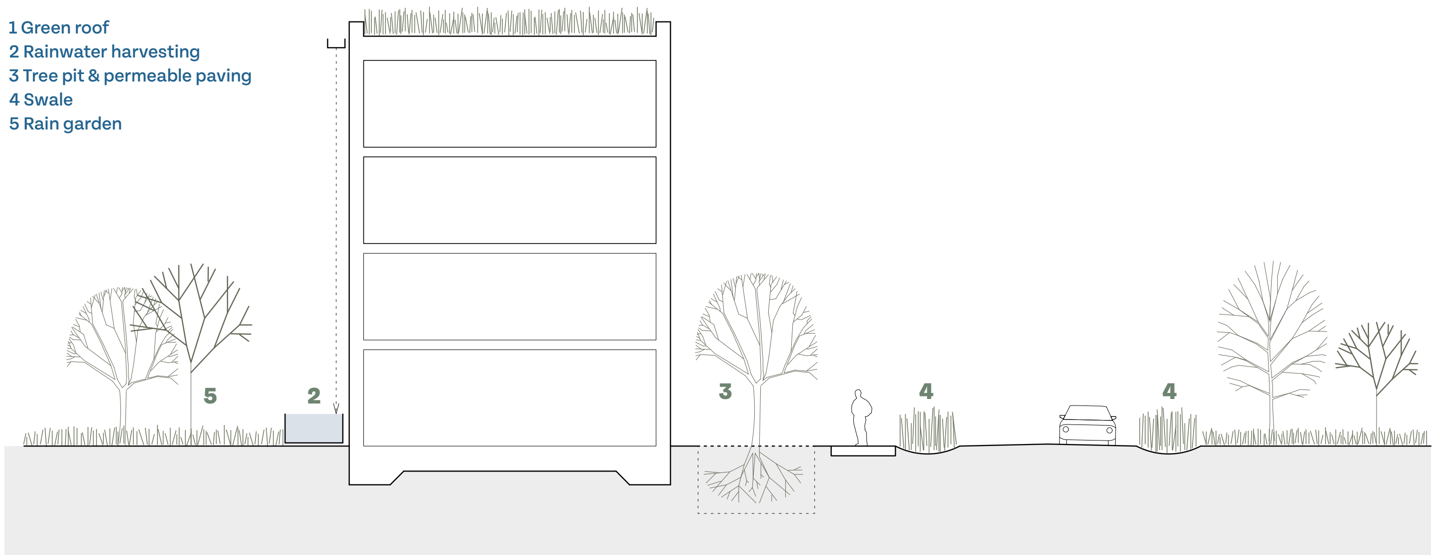
A focus on the landscape around our dwellings reveals large expanses of tarmac, concrete and paved surfaces. Not only do these materials have a high carbon factor, but they also cover soils and vegetation, removing their ability to absorb and hold carbon. Additionally, these impermeable surfaces create surface water run-off during periods of high rainfall that require carbon-intensive systems of drainage and water attenuation. Site planning strategies and urban design layouts that reduce the amount of hard surface associated with vehicle infrastructure are therefore key measures for decarbonising development at an urban level. While good access to public transport and a reduction in the quantum of car parking are important, well-considered site layouts can also provide a more efficient use of materials and infrastructure. Alternatives to parking immediately in front of dwellings should be considered, such as grouping parking spaces or placing them at the short ends of blocks in order to free up areas for pedestrian routes and urban greenery (Fig. 6.31).

The ability of our cities to deal with increased rainfall due to the effects of climate change is key to a resilient future. For urban environments to be climate resilient, they need to work with water rather than seek to channel or displace it elsewhere. Building on new land decreases the quantity of permeable surfaces in a given watershed, and increases water run-off, putting pressure on rivers and local drainage systems. Permeable pavements are now commonly required as part of Sustainable Drainage Systems (SUDS), however the LCA carried out in this study shows a high EC figure of 41 $kgCO_2e/m^2$ for these surfaces, mainly due to the concrete paviours and large quantities of crushed stone aggregate required (Fig. 5.21). Alternative approaches using Nature Based Solutions (NBS) should be considered wherever possible, including swales, soakaways, retention ponds, and reedbeds (Fig. 6.32). Green roofs can absorb and attenuate heavy rainfall, reducing pressure on the urban drainage network, and streets can be designed as permeable shared surfaces, that prioritise space for pedestrians as well as reducing water run-off.

Figures 6.31 Great Kneighton, Cambridge, UK

Figure 6.32 Nature based solutions

1 Green roof
2 Rainwater harvesting
3 Tree pit & permeable paving
4 Swale
5 Rain garden



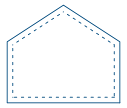
7 CONCLUSION

This study has demonstrated that low-rise, low-density development patterns represent an inefficient use of both land and infrastructure, with consequent increases in embodied carbon emissions. The methodology used shows the importance of incorporating LCAs of external works and infrastructure together with the measurement of building, and suggests that future policy should expand the scope of LCAs for new developments beyond the dwellings themselves to include the entire site. This approach could form part of a more holistic approach to sustainability in the housing sector, that until now has been largely focussed on individual dwellings and the energy they consume.

At a material level, the study suggests that 'easy wins' could be obtained swapping high carbon, fossil fuel materials for recycled or bio-based ones. This approach works even with the standard 'business-as-usual' housing types studied here. The analysis has demonstrated how the choice of structural system affects the EC impact of a building. Low carbon structural systems such as timber frame can provide the benefits of density without incurring a heavy carbon cost. At a neighbourhood scale, the research shows the potential of medium to high density housing typologies to create low energy and climate resilient sustainable communities. This has been described primarily in terms of embodied carbon emissions due to construction, although the potential for positive secondary effects has also been illustrated including reduced car dependency, access to amenities and community services, and the efficient use of precious landscape resources.

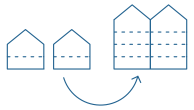
Figure 7.01 Nature-based drainage systems, Hammarby Sjostad, Stockholm

7.10 Recommendations

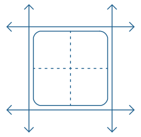


Low-carbon structural materials
Concrete structural elements including foundations have been shown to have a high embodied carbon impact. Consider using concrete based on low carbon cement such as GGBS. Explore opportunities for expanding the use of timber in the Irish construction industry, including changes to regulations that would allow mass timber products to be used for apartment buildings.

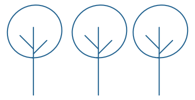
Use Bio-based Products
Bio based materials result from living, or once living, organisms, that sequester carbon that is absorbed as the material grows. Wherever possible, these should be used to replace high-carbon materials produced using fossil fuels. Some examples of such low or zero carbon materials available in Ireland are hempcrete blocks, lime plaster, and insulation products including sheep's wool, cellulose, wood fibre, and cork.



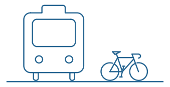
Density
Stacking and clustering buildings into denser forms allows for the efficient use of materials, infrastructure, and landscape. Medium-density low-rise solutions can be achieved using low-carbon timber frame. Apartment buildings are sustainable at an urban scale due to their greater density, but in order to reduce the embodied carbon impact of the buildings themselves low-carbon structural solutions are required.



Reduce vehicle infrastructure
Vehicle infrastructure has a demonstrated high embodied carbon impact so prioritise site layouts that minimise roadways. Favour denser housing typologies such as duplexes and apartments that allow efficient vehicle circulation patterns. Car parking also has a high embodied carbon impact, so consider car-sharing, on-street parking, and the grouping of parking spaces in order to create more efficient layouts.



Incorporate Nature-based Solutions
New developments should maximise the use of Nature-based Solutions such as green roofs, tree-planting, swales, and other bioretention measures. These reduce surface water run-off, and also minimise the amount of drainage infrastructure required. On-site SUDS strategies should require natural drainage solutions to be incorporated wherever possible, instead of relying on conventional carbon intensive drainage systems.



Connect to Public Transport
Choose sites that connect to existing transport infrastructures and nodes where possible. Building at higher densities supports the viability of public transport solutions and active modes of travel. This reduces car dependency with a consequent overall reduction in transport emissions.

8 GLOSSARY OF TERMS

Bio-based Materials
Bio-based materials are obtained from living, or once living, organisms, that could replace high-carbon materials produced using fossil fuels. Bio-based materials can range from traditional construction materials that were used in vernacular architecture, such as thatch, timber or clay, to new technologies, such as mycelium-based insulation, or hempcrete masonry.

Brownfield Site
A brownfield site is one that has been previously built on, and that may require preparatory site clearance or enabling works before it can be re-used. Brownfield sites tend to be located closer to city or town centres than greenfield sites, and may already have good connections to community amenities, or to transport and service infrastructures.

Carbon sequestration
Carbon sequestration and storage is the practice of removing carbon from the atmosphere and storing it. Bio-based materials such as timber will remove carbon from the atmosphere during their growth phases and store it, allowing buildings to be considered as a carbon sink.

Compact Urban Growth
Sustainable urban growth defined by dense development patterns on centrally located or vacant sites, linked by public transport systems that provide accessibility to local services and jobs.

Cross Laminated Timber (CLT)
Cross Laminated Timber is a solid, load-bearing timber panel that is suitable for structural requirements. It is made from several layers of solid wood panels at right angles bonded with a structural adhesive.

Embodied Carbon (EC)
Embodied Carbon is the carbon emitted during the life cycle of a building including from its construction, maintenance, and ultimate demolition and disposal. It does not include operational carbon emissions associated with the running of the building. Embodied Carbon is often thought of as the carbon associated with the construction of a building, and while this is generally the largest contributor to emissions, it is only one part of the life cycle stages included.

Environmental Product Declaration (EPD)
EPDs are independently verified estimates of a product's life cycle environmental impact. They provide product-specific data for carrying out Life Cycle Assessment (LCA) and embodied carbon calculations.

Greenfield Site
A greenfield site is one that has not been previously developed, and is entirely or largely covered by vegetation or natural landscape. The development of greenfield sites is associated with urban sprawl.

Greenhouse Gas (GHG)
Greenhouse gas emissions are those generated by man-made activities that intensify the greenhouse effect and contribute to climate change. Although carbon dioxide from the burning of fossil fuels is the largest polluter, other gases such as methane or nitrogen dioxide also contribute. Instead of counting the contribution of all gases, the equivalent contribution in carbon dioxide is used, measured in KgCO2e.

Ground Granulated Blast-furnace Slag (GGBS)
GGBS (Ground Granulated Blast-furnace Slag) is a cementitious material obtained as a by-product from the blast-furnaces used to make iron. It can be used to reduce the embodied carbon of concrete production.

Life Cycle Assessment (LCA)
Life Cycle Assessment (LCA) is procedure to quantify whole life cycle carbon emissions throughout the various life stages of a building. In the EU the calculation method of LCAs is set out in standard EN 15978.

Nature-based Solutions (NBS)
Nature-based Solutions are climate-resilient strategies that are inspired and supported by nature. They use local and resource-efficient solutions that bring natural features and processes into cities.

Operational Carbon (OC)
Operational carbon emissions are the emissions associated with a building's energy and water use during its running.

PIR Insulation
Polyisocyanurate (PIR) is a type of insulation board, well known for its excellent thermal insulation capabilities. The main components of PIR boards are fossil fuel derivatives resulting in a relatively high embodied carbon.

Typology
In architecture, typology refers to a system for grouping types of buildings according to similar physical characteristics. In housing examples of typologies are a semi-detached house, a three storey duplex, or deck-accessed apartments. A typology is more physically specific the more general term 'type', which might refer generically to 'houses' or 'apartments'.

U-value
The U-value of a material measures how effective it is as an insulator. The lower the U-value, the less heat is lost and the more insulation the material provides.

Urban sprawl
The uncontrolled expansion of urban development characterised by low density, segregated land use and car-dependent transport.

Whole Life Carbon (WLC)
Whole Life Carbon is the carbon emitted throughout a building's entire life cycle, from construction, to operation, to demolition and disposal. It can be thought of as the embodied carbon and operational carbon added together.

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APPENDIX A: DETAILED EMBODIED CARBON RESULTS

All results show upfront embodied carbon for life cycle stages A1-A5

DETACHED HOUSE

Total EC	93,421 kgCO_2e
Dwelling Size	224m^2
EC/m^2	417 kgCO_2e/m^2
EC External Works per Dwelling	N/A

Highest EC by Construction Element: kgCO_2e

External Walls	27,805
Roof Structure + Finishes	24,830
Substructure	16,905
Windows + Doors	5,300
M&E Services	3,808

Highest EC by Material: kg CO2e

Concrete Blockwork	15,066
In-situ Concrete	10,000
Concrete Roof tiles	8,738
Insulation	7,684
Plastic	6,576

SEMI-DETACHED HOUSE

Total EC	41,211kg CO_2e
Dwelling Size	118m^2
EC/m^2	349 kgCO_2e/m^2
EC External Works per Dwelling	7,361 kgCO_2e

Highest EC by Construction Element: kgCO_2e

Substructure	10,113
External Walls	7,159
Roof Structure + Finishes	6,737
Windows + Doors	2,919
M&E Services	2,410

Highest EC by Material: kgCO_2e

Insulation	13,461
In-situ Concrete	8,578
Concrete Blockwork	4,157
Brick	3,903
Concrete Roof tiles	3,381

MEDIUM-DENSITY LOW-RISE/DUPLEX

Total EC for Building	84,948 kgCO_2e
Total number of dwellings	22
Total EC per Dwelling	42,474 kgCO_2e
Dwelling Size	103m^2
EC/m^2	410 kgCO_2e/m^2
EC External Works per Dwelling	2,402 kgCO_2e

Highest EC by Construction Element: kgCO_2e

Substructure	20,394
External Walls	14,662
Roof Structure + Finishes	6,737
Windows + Doors	7,742
Internal Walls + Partitions	7,050

Highest EC by Material: kgCO_2e

Concrete Blockwork	25,650
Insulation	15,981
In-situ Concrete	15,235
Brick	13,629
Plasterboard	3,983

APARTMENT BUILDING

Total EC for Building	908 tonnes CO_2e
Total number of dwellings	22
Total EC per Dwelling	41,289 kgCO_2e
Dwelling Size	93m^2
EC/m^2	445 kgCO_2e/m^2
EC External Works per Dwelling	1,889 KgCO_2e

Highest EC by Construction Element: Tonnes CO_2e

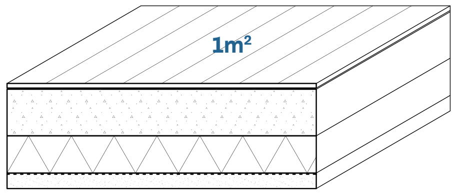
Substructure	80
External Walls	108
Roof Structure + Finishes	60
Upper Floor Slabs	121
Internal Walls + Partitions	134

Highest EC by Material: kgCO_2e

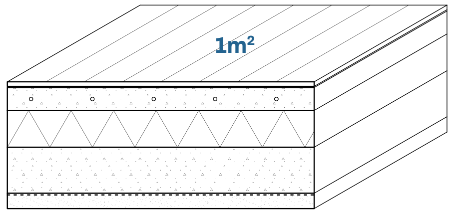
In-situ Concrete	325
Concrete Blockwork	156
Hollow-core Concrete Slabs	138
Brick	96
Cement and Mortar	75

APPENDIX B: TYPICAL CONSTRUCTION BUILD-UPS

Ground Floors

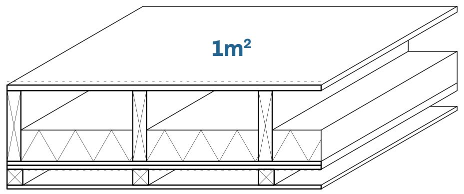


SEMI-DETACHED HOUSE
15mm engineered wood floor
4mm high density foam underlay
150mm RC slab with power-floated finish
120mm PIR insulation (0.022W/m2K)
DPM and Radon barrier
50mm clean sand blinding
150mm min hardcore (aggregate)

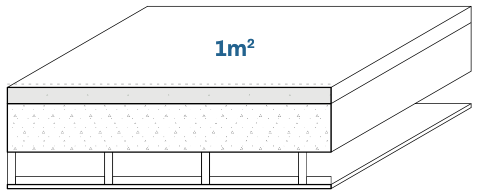


DETACHED HOUSE
15mm engineered wood floor
4mm high density foam underlay
75mm concrete screed with heating pipework
120mm PIR insulation (0.022W/m2K)
150mm RC slab with power-floated finish
DPM and Radon barrier
50mm clean sand blinding
150mm min hardcore (aggregate)

Upper Floors

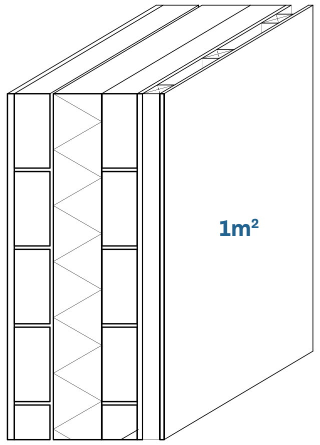


SEMI-DETACHED & DETACHED HOUSE
15mm engineered wood floor
4mm high density foam underlay on
18mm WPB plywood
225x44 joists @ 400mm centres
100mm mineral wool between joists
2 layers 15mm fireline board
Airtight membrane
50x50mm counterbattens
12.5mmm plasterboard and skim

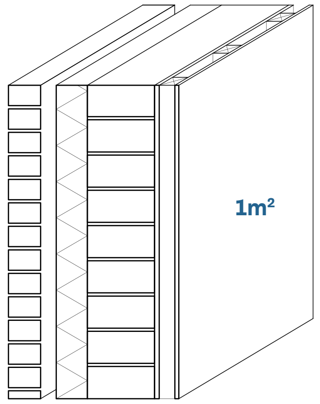


SUBURBAN APARTMENTS
15mm engineered wood floor
4mm high density foam underlay
50mm floor screed on
150mm precast hollowcore slab on
100mm service void - Gyproc MF ceiling system
12.5mmm plasterboard and skim ceiling

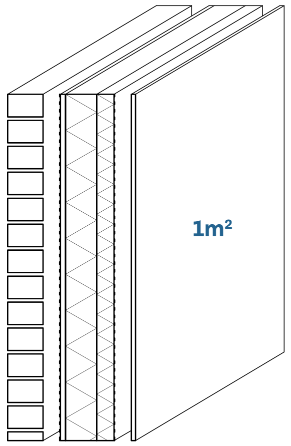
External Walls



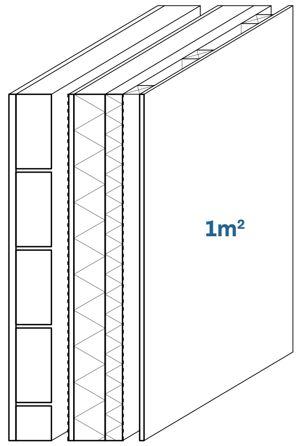
DETACHED HOUSE & DUPLEX–RENDER
20mm sand cement render (6:1:1)
102.5mm concrete blockwork
10mm residual cavity
140mm PIR insulation
Stainless steel wall ties
102.5mm concrete blockwork
15mm wet plaster airtight layer
50mm timber studs forming service void
12.5mmm plasterboard and skim



SUBURBAN APARTMENTS–BRICK
102.5mm brickwork
50mm residual cavity
100mm PIR insulation
Stainless steel wall ties
215mm concrete blockwork
15mm wet plaster airtight layer
50mm timber studs forming service void
12.5mmm plasterboard and skim



SEMI-DETACHED HOUSE–BRICK
102.5mm brickwork
50mm cavity
Breathable membrane (EPD: Exoperm mono 150)
15mm o.s.b. board
90mm timber studs with PIR insulation between studs
50mm PIR insulation board
Vapour control membrane (EPD: Izoperm plus)
50mm timber studs forming service void
12.5mmm plasterboard and skim



SEMI-DETACHED HOUSE–RENDER
20mm sand cement render (6:1:1)
102.5mm concrete blockwork
50mm cavity
Breathable membrane (EPD: Exoperm mono 150)
15mm o.s.b. board
90mm timber studs with PIR insulation between studs
50mm PIR insulation board
Vapour control membrane (EPD: Izoperm plus)
50mm timber studs forming service void
12.5mm plasterboard and skim

The housing crisis and the climate crisis are intertwined, and we cannot solve one without addressing the other. This research studies the environmental impact of new housing construction in Ireland by assessing the carbon emissions of different dwelling types at a range of scales and densities, from individual houses to duplex dwellings and apartments. Current policy in Ireland focuses mainly on the emissions created by the running of buildings, known as operational carbon and measured through the Building Energy Rating (BER) system. Less well understood is the carbon emitted through the construction and maintenance of buildings, known as embodied carbon. The research addresses this gap by assessing the embodied carbon emissions and other environmental impacts created by new construction. By gaining an understanding of the climate impacts of current building practices, strategies for a decarbonised housing sector are then proposed. This evidence-based knowledge will provide developers, policy makers and housing stakeholders with a platform to imagine the low-carbon communities of the future.

An Ghníomhaireacht Tithíochta
The Housing Agency