Structural requirements for the mounting of solar plants on roofs and in open areas

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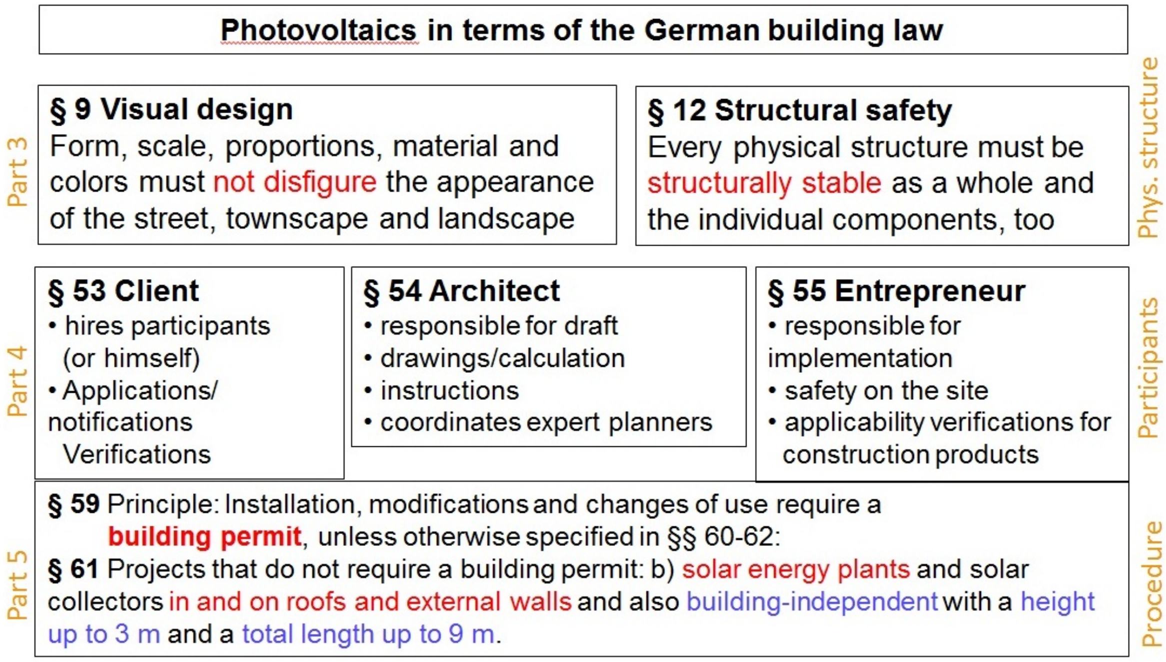
Overview

Photovoltaic plants for the generation of solar energy are exposed to the climatic conditions at the respective installation location. Wind, snow and temperature impacts create stresses that the modules and the rack components have to withstand reliably. In terms of the building law, a photovoltaic plant is regarded as part of a building or a building of its own. Thus, the relevant regulations of constructional engineering have to be considered. This requirement leads to the need for a structural dimensioning according to the generally accepted rules of building and construction. Besides the planning requirements, also the quality and certification requirements laid down in the Construction Products Directive apply. For all products that are not included in the Building Products List and that can not be structurally verified on the basis of established technical sets of rules, general technical approvals have to be presented or project-specific approvals from the supreme construction authorities of the federal states have to be obtained.
With solar plants that are installed on or to buildings, also the structural safety of the building considering the additional loads caused by the photovoltaic plant has to be verified. With solar plants that are installed parallel to the roof or to the walls, additional wind and snow loads do not have to be considered. Elevated plants lead to additional loads resulting from wind and snow that have to be verified within the framework of a structural analysis of the existing building.

1. Introduction

In the sense of the building law and the building codes of the federal German states, a photovoltaic plant is to be regarded as part of a building or as a building of its own. As a result of that, the client on whose behalf a solar plant is installed is obliged to adhere to the binding regulations of the building law.



Picture 1 Classification of photovoltaic installations in terms of the building law

On picture 1, the fundamental requirements of the Model Building Regulation are compiled that apply for the installation of photovoltaic plants. Besides the design regulations that determine that a building has to fit in visually in its surrounding, the structural safety of the complete plant and its individual components has to be pointed out as a decisive criterion. As the client on whose behalf the solar plant is installed usually does not have the expertise to carry out the planning and mounting, he hires partners like the draft creator (architect) and the executing entrepreneur. In many cases, both tasks are fulfilled by one and the same installation company. By doing so, the installation company assumes responsibility for the structural safety of the solar plant and the exclusive use of approved products. In practice, usually the rack manufacturer provides the verification of structural safety of the mounting system. The verification of the structural safety of the building considering the additional loads caused by the photovoltaic plant remains in the area of responsibility of the client. In this matter, engineering offices focussing on structural design should be consulted. Even though the Model Building Regulation defines projects that are not subject to approval, the client is still responsible for the adherence to the relevant regulations. By issuing an amendment, numerous states of the federal republic of Germany have concretized the obligation to obtain an approval for elevated solar plants on roofs.

2. Load assumptions

The determination of the loads is carried out on the basis of the relevant parts of the DIN 1055 respectively the DIN EN 1991 (Eurocode 1) with country-specific attachments that will replace the DIN 1055 in the course of the harmonization of the technical rules and standards.

Permanent loads (self-weight g)

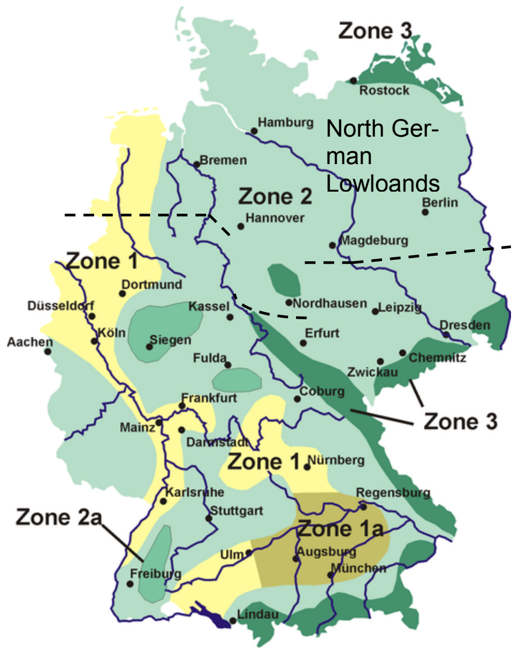
The self-weight g of the complete construction is mainly determined by the weight of the modules. The weight of the substructure is negligibly low, but it can be determined by multiplying the cross section area of the load-bearing profile with the specific density of the aluminum material. The weight of the module is specified in the data sheet by the manufacturer.

Snow loads (s)

The determination of the snow loads depends on the following influencing factors:

- Snow load zone map
- Height of the project location above sea level
- Module inclination
- Higher roof areas

The map alongside (picture 2) corresponds to the data included in the DIN EN 1991-1-1-3/NA (04/07). It shows the subdivision of the Federal Republic of Germany in 3 snow load zones. The location-specific snow loads on the ground have to be determined depending on the snow zone using the following equations:



Picture 2 Snow zone map

Zone 1: $s_k = 0.19 + 0.91 \cdot \left(\frac{A+140}{760}\right)^2$ at least 0.65 kN/m^2

Zone 2: $s_k = 0.25 + 1.91 \cdot \left(\frac{A+140}{760}\right)^2$ at least 0.85 kN/m^2

Zone 3: $s_k = 0.31 + 2.91 \cdot \left(\frac{A+140}{760}\right)^2$ at least 1.10 kN/m^2

A Height of the project location above sea level

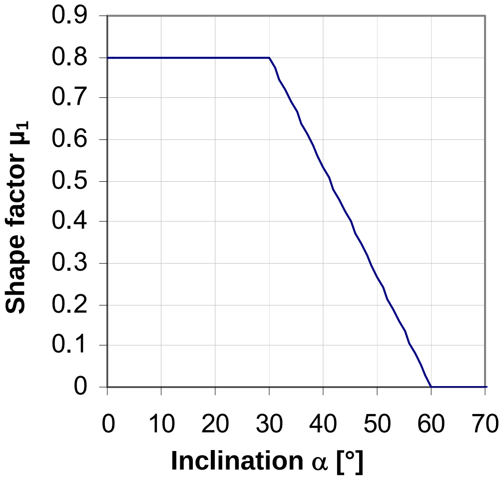
The snow loads in the zones 1a and 2a have to be determined by multiplying the values of the zones 1 and 2 by the factor 1.25. These regulations apply up to a height above sea level up to 1500 m. For higher locations, the snow load data have to be obtained from the authorities in charge. In the North German Lowlands (picture 2), there also an extraordinary load case with a 2.3-fold value of the snow load has to be considered. But here, different partial safety coefficients and combination coefficients are to be used, so that this special case only leads to slightly higher total loads. For the determination of the design snow loads, the snow loads on the ground s_k have to be multiplied by a form coefficient μ_1 depending on the roof inclination respectively the module inclination α. These form coefficients are:

$\alpha \leq 30°$	$\mu_1 = 0.8$
$30° < \alpha \leq 60°$	$\mu_1 = 0.8 \cdot (60 - \alpha)/30$
$\alpha > 60°$	$\mu_1 = 0$

The calculation value for the snow load is.

$$\mathbf{s = s_k \cdot \mu_1}$$

This stands for a vertical snow load on a horizontal area. This snow load can be assumed if there is no neighbouring higher roof from which snow could slide off. In such cases, more exact detail inspections are required.

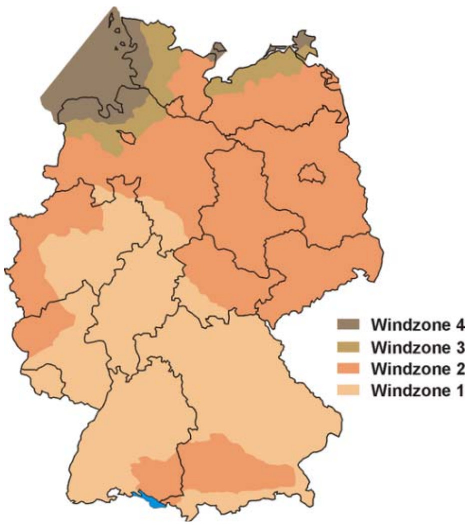


Picture 3 Form coefficient

Wind loads (w)

The wind loads have to be differentiated in wind pressure and wind suction. In the first step, the wind velocity pressure is determined. This value must not be mixed up with the wind loads. Squall velocity pressure (dynamic pressure) is the pressure that is caused by the air that is moved with a defined velocity in the impact pressure flow area.

Table 1 Velocity pressures according to the simplified procedure



Picture 4 Wind zone map

wind zone		peak velocity pressure		
		h ≤ 10 m	10 m < h ≤ 18 m	18 m < h ≤ 25 m
1	inland	0,50	0,65	0,75
2	inland coast an island of East Sea	0,65 0,85	0,80 1,00	0,90 1,10
3	inland coast an island of East Sea	0,80 1,05	0,95 1,20	1,10 1,30
4	inland coast an island of East Sea islands of North Sea	0,95 1,25 1,40	1,15 1,40	1,30 1,55

With the simplified procedure according to DIN 1055-4 (03/05), a stepwise increase of the impact pressure is to be assumed. The threshold levels are 10 m and 18 m. With heights above 25 m, the more exact procedure has to be applied. With the simplified procedure, the maximum building height is used as a reference height for the determination of the simplified velocity pressure (impact pressure). The actual wind load impacting a component depends on the aerodynamic characteristics of the component that is exposed to wind flow. For the determination of the wind load, the simplified velocity pressure is multiplied by the aero-dynamic coefficients according to table 1.

$w_e = c_{pe} \cdot q(z_e)$

with c_{pe} aero-dynamic coefficient (depending on the building geometry)

$q(z_e)$ velocity pressure

With solar roof plants, the dimensions of the solar generator are usually not quite as important as the dimensions of the building. In this case, the overall flow properties of the building are more decisive than the local characteristics of the solar plants. Picture 5 shows a compilation of the most frequent application cases for PV plants. With roof and facade plants clinging to the building envelope, there will be no additional unfavourable wind and snow loads caused by the solar plant. In this case, the pressure coefficients laid down in the DIN 1055 part 4 (07/05) for different basic building forms can be applied without restrictions. However, with elevated solar plants on roofs, solar plants in open areas and carport plants, the situation is different.


Parallel to a pitched roof


Isotop elevated


Alulight with little superimposed load


Open area plants


Carport plants

Picture 5 Plant categories for photovoltaic plants (Schletter solar mounting GmbH)

In the following, the regulations for the determination of wind loads for gabled roofs and monopitch roofs are compiled exemplarily. As the building is to be regarded as an obstacle to the windflow, there will be suction peaks at the roof edges and especially in the roof corner areas that have to be considered by using increased load assumptions. The standardized suction coefficients are laid down in the DIN 1055-4 (03/05) for different roof zones (picture 6):

F corner zone

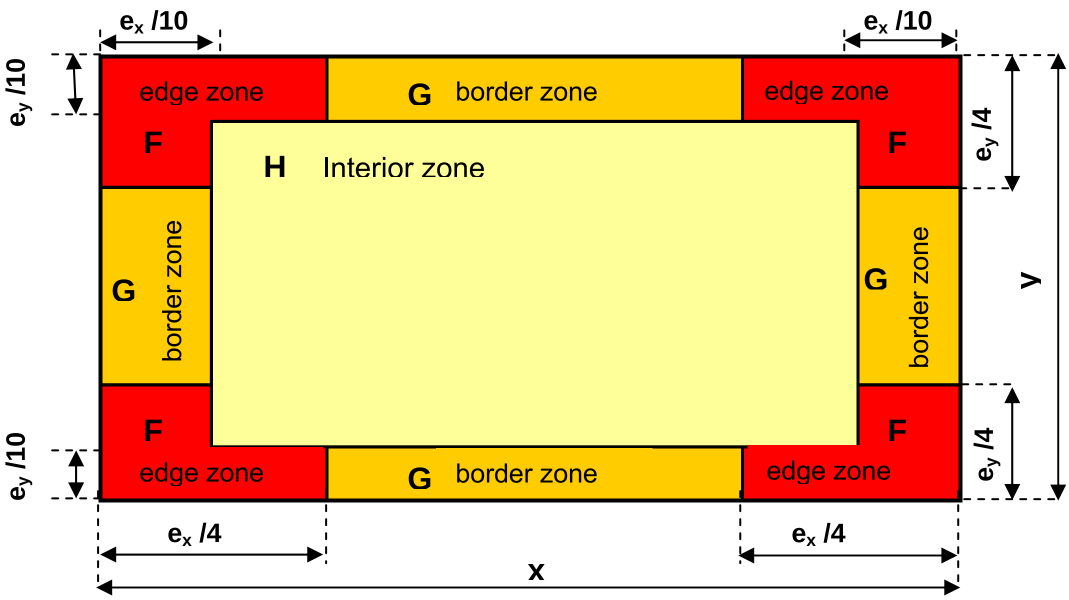
G edge zone

H interior zone

The values e_x and e_y either depend on the building dimensions or the building height h (ridge height):

$e_x = \min(x;2\cdot h)$ $e_y = \min(y;2\cdot h)$

In table 2, the pressure coefficients for the zones F, G, and H (a minus-sign stands for suction) for the ridge roof and the monopitch roof configuration are specified. This is a summary of the normative regulations that were created for wind inflow from different directions. As the wind can impact the building from several directions, always the worst case has to be considered.



Picture 6 Subdivision of the roof zone areas for ridge roofs and monopitch roofs.

Table 2 Pressure coefficients for ridge roofs and monopitch roofs

	ridge roof				monopitch roof			
α	Zone F c_{p10}	Zone G c_{p10}	Zone H c_{p10}	pressure	Zone F c_{p10}	Zone G c_{p10}	Zone H c_{p10}	pressure
0	-2,00	-1,25	-0,70	0,20	-1,80	-1,20	-0,80	0,20
5	-1,70	-1,30	-0,70	0,20	-2,30	-1,80	-0,80	0,20
15	-1,30	-1,30	-0,60	0,20	-2,50	-1,90	-0,80	0,20
30	-1,10	-1,40	-0,80	0,40	-2,10	-1,50	-1,00	0,40
45	-1,10	-1,40	-0,90	0,60	-1,50	-1,40	-1,00	0,60
60	-1,10	-1,20	-0,80	0,70	-1,20	-1,20	-1,00	0,70
70	-1,10	-1,20	-0,80	0,80	-1,20	-1,20	-1,00	0,80

Due to the limited spatial extent of a squall, the pressure coefficients are differentiated for effective load influence zones A = 1 m² and A = 10.0 m². According to the picture below, bigger pressure coefficients have to be assumed for small effective load influence zones. The increased values c_{p1} apply for the connections of the modules. With solar generators that have an interconnected support rack, usually the pressure coefficient c_{p10} are decisive.

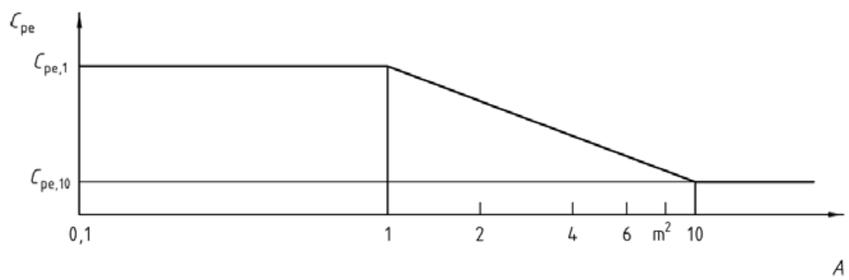
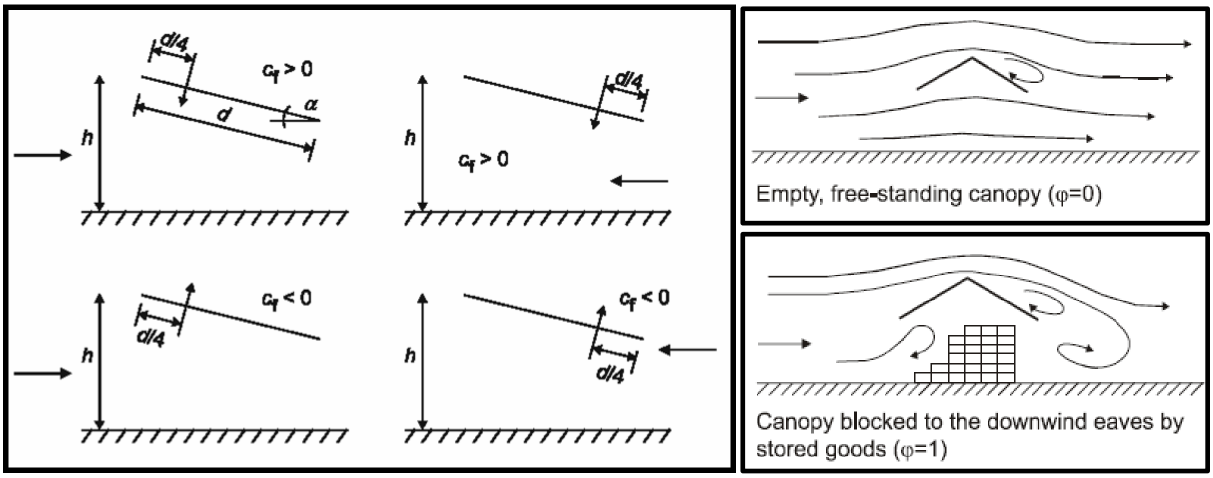


Figure 7 Influence of the effective load influence zone

The DIN 1055-4 does not include any explicit regulations regarding elevated systems on roofs and on the ground (carports and open area plants). According to the NABau (German civil engineering standards committee) the regulations on self-supporting roofs of the Eurocode 1 (EN 1991-1-4) can be used. The pressure coefficients for the structural verification of the roof structure (not shown here) are determined using a similar system like the one for monopitch roofs, but due to the wind flow from below, these values are significantly higher. For the structural verification of the substructure of carports and solar plants in open areas and the structural verification of the fastening of solar plants to the roof cladding, force coefficients according to table 3 in combination with picture 8 are to be used. The positioning of the total wind load in the quarter points of the roof is determined mainly according to the wind flow properties of the roof, and also considering the danger of vibrations.



Picture 8 Load assumptions for self-supporting roofs according to EN 1991-1-4

Table 3 Force coefficients c_f for self-supporting roofs according to EN 1991-1-4

	Inclination angle α						
	0°	5°	10°	15°	20°	25°	30°
pushing	0.2	0.4	0.5	0.7	0.8	1.0	1.2
uplifting φ = 0	-0.5	-0.7	-0.9	-1.1	-1.3	-1.6	-1.8
uplifting φ = 1	-1.3	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4

The load assumption described above is a conservative solution, especially for roof plants, as the mutual shading of rows behind each other which reduces the wind loads is not considered. Wind tunnel tests suggest that there are much more economic solutions. As no systematic tests have been carried out yet, a general standardization of the results is not possible yet.

3. Load combinations

According to the regulations laid down in the DIN 1055-100, the concept of the divided safety coefficients has to be considered. Thus, the load impacts have to be multiplied by specific partial safety coefficients. The following conventions apply:

γ_g = 1.35 for unfavourable permanent loads (own weight of the structure)

γ_g = 0.9 for favourable permanent loads (in combination with wind suction)

γ_q = 1.5 for changing loads (wind and snow)

The load assumptions for wind and snow apply for the specific event that occurs once or is exceeded once within an observation period of 50 years. As it is very unlikely that the most unfavourable snow event and the most unfavourable wind event will occur at the same time, the wind and snow loads can be reduced using so-called combination coefficients.

$\psi_{0,w}$ = 0.6 Combination coefficient with snow as the main impact and wind

$\psi_{0,s}$ = 0.5 Combination coefficient with wind as the main impact and snow

The regulations described above result in the following load combinations:

Load combination 1: $\gamma_g \cdot g + \gamma_q \cdot s + \psi_{0,w} \cdot \gamma_q \cdot w = 1.35 \cdot g + 1.5 \cdot s + 0.6 \cdot 1.5 \cdot w$

Load combination 2: $\gamma_g \cdot g + \psi_{0,w} \cdot \gamma_q \cdot s + \gamma_q \cdot w = 1.35 \cdot g + 0.5 \cdot 1.5 \cdot s + 1.5 \cdot w$

Load combination 3: $\gamma_g \cdot g + \gamma_q \cdot w_{suction} = 0.9 \cdot g + 1.5 \cdot w_{suction}$

In the North German Lowlands, an additional load combination must be taken into account:

Load combination 1 a: $\gamma_{g,A} \cdot g + \gamma_{q,A} \cdot s = 1.0 \cdot g + 2.3 \cdot s$

Only if this extraordinary load combination leads to higher values than the load combination LK1, it is to be used instead of the load combination 1 for the verification of structural safety.

4. Check of the constructional situation

An essential part of the project planning is to check whether or not the building or the building ground (open area/carport) can take the load of a photovoltaic plant. With roof-parallel solar plants, this can be checked in many cases by load comparisons and checks of excess load-bearing capacities on the basis of the structural analysis of the existing building. With elevated plants, this task is more painstaking, as the solar generator puts considerably heavier loads caused by the wind onto the roof that have to be transmitted safely into the substructure respectively into the subsoil by means of reinforcements of the building. For the determination by calculation of the wind shading of rows that are positioned behind each other (which reduces the wind loads), there are no normative regulations, so that engineer´s assumptions have to be made. Building owners are usually reluctant to posterior reinforcement measures. Moreover, such measures make the project more expensive. Nevertheless, the verification of the structural safety of the building considering the additional loads caused by the photovoltaic plant is compulsory.

5. Summary

In the sense of the building law, a photovoltaic plant on a building or on the ground is defined as a part of a building or as a building of its own. Besides other legal preconditions, this leads to the requirement of a verification of the structural safety of the mounting rack and the connections of the load-bearing structure to the building or the construction ground as well as the structural safety of the building that has to bear the load of the solar plant. The determination of the relevant load impacts on buildings resulting from self-weight, wind and snow is regulated in the DIN 1055. The snow load on the ground and the squall velocity pressure generally can be regarded as correct, independently of photovoltaic installations. However, regarding the additional snow loads on the roof caused by elevated solar plants as well as the accordant pressure coefficients, assumptions have to be made. The determination of the wind loads by analogy observations based on the basic building forms defined in the DIN 1005-4 usually results in values on the safe side that lead to problems regarding the verifications of structural safety of buildings. For the determination of more exact values, the DIN 1055-4 explicitly allows wind tunnel tests in boundary layer wind tunnels at the institutes that are organized in the WTG (German Association for wind technology). According to current experience, these more precise results allow a more economic project planning.